

New York State Water Resources Institute Annual Technical Report FY 2008

Introduction

The Mission of the New York State Water Resources Institute (WRI) is to improve the management of water resources in New York State and the nation. As a federally and state mandated institution located at Cornell University, WRI is uniquely situated to access scientific and technical resources that are relevant to New York State's and the nation's water management needs. WRI collaborates with regional, state, and national partners to increase awareness of emerging water resources issues and to develop and assess new water management technologies and policies. WRI connects the water research and water management communities.

Collaboration with New York partners is undertaken in order to: 1) Build and maintain a broad, active network of water resources researchers and managers, 2) Bring together water researchers and water resources managers to address critical water resource problems, and 3) identify, adopt, develop and make available resources to improve information transfer on water resources management and technologies to educators, managers, and policy makers.

Research Program Introduction

WRI's FY08 competitive grants research program was conducted in partnership with the NYS Department of Environmental Conservation and the Hudson River Estuary Program (HREP). The specific areas of interest for the FY2008 grants program were: 1) Research that addresses key knowledge gaps or issues of emerging importance; 2) Projects that integrate technical, legal and social expertise to promote innovative, watershed management strategies; and 3) Development of novel methods for knowledge transfer that enhance the communication of scientific research to teachers, technical providers or to watershed communities. Projects were evaluated by a panel consisting of representatives of other water resources institutes in the northeast, non-governmental organizations, the NYS Department of Environmental Conservation (DEC), and faculty from Cornell University. In total, six research projects were supported in FY08 through the competitive grants program with a total funding level of \$97,010 (\$49,000 USGS 104B, \$47,011 HREP). These projects included:

- Application of stream landscape theory for the restoration of Hudson Valley Watersheds, PI Dr. Mark Bain, Natural Resources, Cornell University;
- Multimedia modeling of regional variation of nitrogen sources in the Hudson River Watershed, PI Dr. Robert Howarth, Ecology & Evolutionary Biology, Cornell University;
- Prediction of areas sensitive to fertilizer application in thinly soiled Karst, PI Dr. Paul Richards, SUNY College at Brockport;
- Best management practices for managing stormwater runoff from developing areas in the Hudson River Valley, PI Dr. Tammo Steenhuis, Biological and Environmental Engineering, Cornell University;
- Potential impacts of climate change on sustainable water use in the Hudson River Valley, PI Dr. Allan Frei, Department of Geography, Hunter College, and City University of New York Institute for Sustainable Cities.
- Evaluation of sediment sources in the Hudson River Watershed, PI Todd Walter, Biological and Environmental Engineering, Cornell University.

Multimedia modeling of regional variation of nitrogen sources in the Hudson River Watershed

Basic Information

Title:	Multimedia modeling of regional variation of nitrogen sources in the Hudson River Watershed
Project Number:	2008NY103B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	22
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Quality, Nutrients, Models
Descriptors:	None
Principal Investigators:	Robert W Howarth

Publication

1. Howarth, R. W. 2008. Coastal nitrogen pollution: A review of sources and trends globally and regionally. Harmful Algae. 8:14-20.
2. Howarth, R. W. 2008. Estimating atmospheric deposition in the northeastern United States: Relevance to Narragansett Bay. Pages 43-61 in A. Desbonnet and B. A. Costa-Pierce (eds.), Science for Ecosystem Based Management. Springer, NY.
3. Swaney, D.P., D. Scavia, R.W. Howarth and R.M. Marino. 2008. Estuarine classification and response to nitrogen loading: Insights from simple ecological models, Estuarine, Coastal and Shelf Science. doi:10.1016/j.ecss.2007.09.013
4. Boyer E. W. & R. W. Howarth 2008. Nitrogen fluxes in rivers to the coastal oceans. Chapter 36, pp. 1565-1584, in: Capone DG, D Bronk, M Mulholland, and EJ Carpenter (eds.), Nitrogen in the Marine Environment, 2nd edition, Academic Press, San Diego, 1668pp.

**FINAL REPORT TO THE
NEW YORK STATE WATER RESOURCES INSTITUTE**

**Current and projected patterns of regional variation of nitrogen sources
in the Hudson River watershed**

Dennis P. Swaney, Bongghi Hong, and Robert W. Howarth

Project Duration: March, 2008-February, 2009.

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PROBLEM STATEMENT AND RESEARCH OBJECTIVES

In regions such as the Hudson watershed, subject to changes in land use and in atmospheric deposition of nitrogen, the processes that control nutrient loads to the estuary are complex. These hydrological and biogeochemical processes are further complicated by regional weather and climate change. Understanding how these processes affect the magnitude and transformations of the nutrient loads is necessary in order to manage the environmental resources of the coastal zone. Further, it is important for those living in and managing coastal watersheds to understand the impacts of their activities and policies on these nutrient loads. Simple modeling tools that can integrate the patterns of atmospheric deposition and other sources with landscape processes in the watershed can improve our ability to manage and communicate the effects of human activities and environmental processes on nutrient loads. The report of the National Academy of Science's Committee on Causes and Management of Coastal Eutrophication noted that most models used by watershed and estuarine managers fail to deal adequately with nitrogen deposition onto the landscape with subsequent export downstream, even though this is the dominant input of nitrogen to many estuaries. The Committee further concluded that the development of such a model – particularly one that deals with atmospheric deposition -- is one of the most pressing priorities for solving the problem of coastal eutrophication (NRC 2000). We used a model (ReNuMa) developed in response to this need, together with seasonal projections from EPA's CMAQ atmospheric deposition model, to address this need in the Hudson watershed and estuary.

Work over the last year has focused on five areas:

- Using the watershed deposition tool and GIS software to estimate components of atmospheric deposition to the Hudson/Mohawk watershed from EPA's CMAQ model
- Compiling and organizing population data and agricultural census data necessary for estimating nitrogen inputs to the Hudson/Mohawk watershed
- Compiling and organizing weather data for stations within or near the Hudson watershed appropriate for driving hydrological simulation
- Creating an accounting tool (NANI calculator) for estimating nitrogen inputs to subwatersheds from population, agronomic and atmospheric deposition data
- Simulating annual variation hydrology and N fluxes in the major subbasins of the Hudson/Mohawk

Each of these areas is discussed in more detail in the sections below

METHODOLOGIES

All project work was conducted on the Cornell campus using existing resources (computer hardware, GIS software, and models developed in-house) and datasets available online from public sources.

Datasets.

1) Nitrogen datasets based on census data, etc. The nitrogen inputs used within ReNuMa include atmospheric deposition (originating from fossil-fuel combustion), fertilizer use, nitrogen in human

waste and animal manure, and biological N₂ fixation associated with agricultural crops. County level fertilizer use was obtained from a national dataset (Ruddy et al., 2006). Population data was obtained at the county level from the US census bureau; livestock data at the county-level data from the USDA National Agricultural Statistics Service. Corresponding county level livestock and crop production data were obtained from USDA's agricultural census using procedures outlined in the NANI calculator documentation (Appendix 1). Agricultural N₂ fixation rates in cultivated crop lands by multiplying the area of N-fixing species by literature-derived N fixation rates (6). Areas of the major N-fixing crops grown in the watershed (soybeans, alfalfa, hay, pasture, and snap beans) are from agricultural census data. Atmospheric deposition data has been obtained from seasonal output of the CMAQ model using the Watershed Deposition Tool publicly available online at: <http://www.epa.gov/amad/EcoExposure/depositionMapping.html> , and directly from the CMAQ modeling group.

2) Weather data for stations within or near the Hudson watershed. A basic task required for hydrological simulations of any watershed is to compile and process basic climatic data necessary to drive the model in the desired watersheds. For this purpose, we used daily weather data from individual weather stations in the National Climate Data Center network (<http://cdo.ncdc.noaa.gov/CDO/dataproduct>) that fell in or near each hydrologic unit of the Hudson/Mohawk basin. Data were downloaded from the NOAA NCDC website, and then processed to determine gaps, erroneous data, etc. The download procedure that was followed is outlined in Appendix 1. Following download, the datasets were organized in excel spreadsheets, and processed using excel macros. These are detailed in Appendix 2.

GIS analysis. GIS (ArcGIS 9.2) was used to assign county level data to individual watersheds based on the fraction of county area falling in each watershed (5). Protocols for many of these procedures have been made available online (http://www.eeb.cornell.edu/biogeonanc/GIS_methods/GIS_methods.htm).

GIS was also used to analyze output from the CMAQ model to estimate total deposition of oxidized (wet and dry) nitrogen onto the watersheds of the Hudson River basin. Area-weighted atmospheric deposition estimates are based on seasonal or annual outputs of either total or oxidized components of nitrogen deposition from the CMAQ model (http://gcmd.nasa.gov/records/CMAQ_Model.html). We have used deposition estimates of multiple constituents on both a 36 km grid-cell basis and a 12 km grid-cell basis for the year 2002. CMAQ deposition estimates at the grid scale were transformed into subwatershed estimates following existing procedures (http://www.eeb.cornell.edu/biogeonanc/GIS_methods/GIS_methods.htm) and formatted for input to NANI calculations and for ReNuMa.

Modelling and analysis. In addition to data processing with GIS and other tools, the project has made use of three major modeling tools, two of which have been developed by our group:

- USGS fluxmaster software, a statistical tool which estimates nutrient fluxes from streamflow data and nutrient concentration data. These estimates are considered the standard approach for estimating fluxes, and are used to validate other model estimates of nutrient fluxes
- The NANI toolbox, which includes three tools for downloading data and calculating nitrogen inputs to watersheds. This toolbox has been developed in response to the need for

estimating nutrient inputs to the Hudson/Mohawk and other watersheds. The toolbox is being made available online, together with its documentation, at:

<http://www.eeb.cornell.edu/biogeonanc/nani/nani.htm>

- The Regional Nutrient Management Model (ReNuMa) which couples estimates of nitrogen inputs to watersheds with a large-watershed scale hydrological model to estimate nitrogen export from the watershed. The model was used to estimate nitrogen fluxes in the Hudson. The model is available for download at: <http://www.eeb.cornell.edu/biogeonanc/usda/renuma.htm>

Information transfer. The primary mode of dissemination of the model and associated information (user's guide, datasets, etc) has been via the internet. GIS datasets developed by the project for modeling subwatersheds in the region, including digital elevation, soil, land use/land cover, atmospheric deposition data, and derived coverages are being made available for public use by placing them in the CUGIR data depository at Mann Library (<http://cugir.mannlib.cornell.edu/>). Protocols for analyzing the dataset using GIS and other methods have been posted on the protocol website (http://www.eeb.cornell.edu/biogeonanc/GIS_methods/GIS_methods.htm). As mentioned previously, the ReNuMa model, including the data specific to individual watersheds, is being made available on the ReNuMa website. We are in the process of publishing the relevant results on the Hudson watershed, and have presented ongoing work at scientific conferences (see notable achievements, below).

PRINCIPAL FINDINGS AND SIGNIFICANCE

Observed temporal patterns of hydrology and nutrient fluxes. The average seasonal pattern of hydrology in the Upper Hudson and Mohawk is shown in figure 1, based on USGS measurements at gauging stations at Cohoes (Mohawk) and Waterford (Upper Hudson). Peak flow occurs April, concurrent with spring snowmelt and runoff. Minimum flows occur in the summer months. Slightly lower flows (per area) occur in the Mohawk, probably due to greater evapotranspiration from this agricultural watershed. The Upper Hudson has a higher proportion of forest cover than the Mohawk. Interrannual variation of streamflow (figure 2) over several decades show fluctuations with periods of three to four years. Corresponding patterns in nitrogen fluxes (figure 3) appear to be hydrologically driven. Because annual hydrology in the catchment is governed by the balance between precipitation and evapotranspiration, it is evident that both streamflow and nutrient fluxes will respond to climate changes, such as changes in seasonal and annual mean temperature and rainfall patterns.

Figure 1. The Upper Hudson and Mohawk drainages exhibit very similar seasonal patterns of discharge; a strong seasonal peak in April, related to spring runoff, followed by low discharges in the summer. While the overall patterns are similar, summer low discharges in the Mohawk (Cohoes) are consistently and significantly lower than those of the Upper Hudson (Waterford). The subbasins differ in that the Upper Hudson is further north and contains more forest and mountainous terrain than the Mohawk, which has a significant agricultural proportion of land cover.

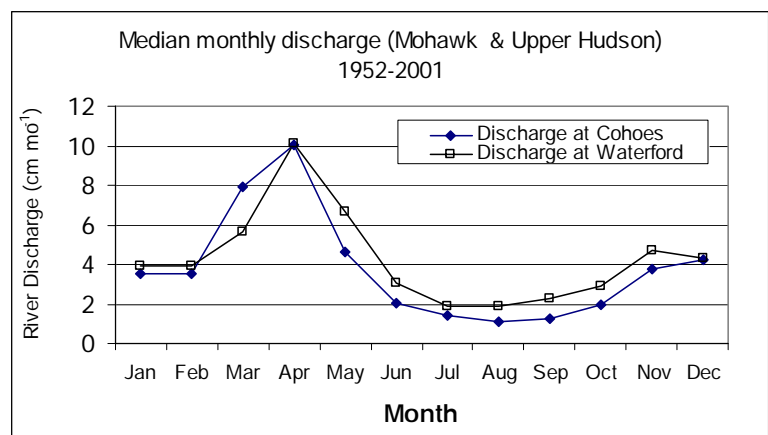


Figure 2. Interannual variation of annual streamflow measurements at some USGS gauging stations in the Hudson/Mohawk system.

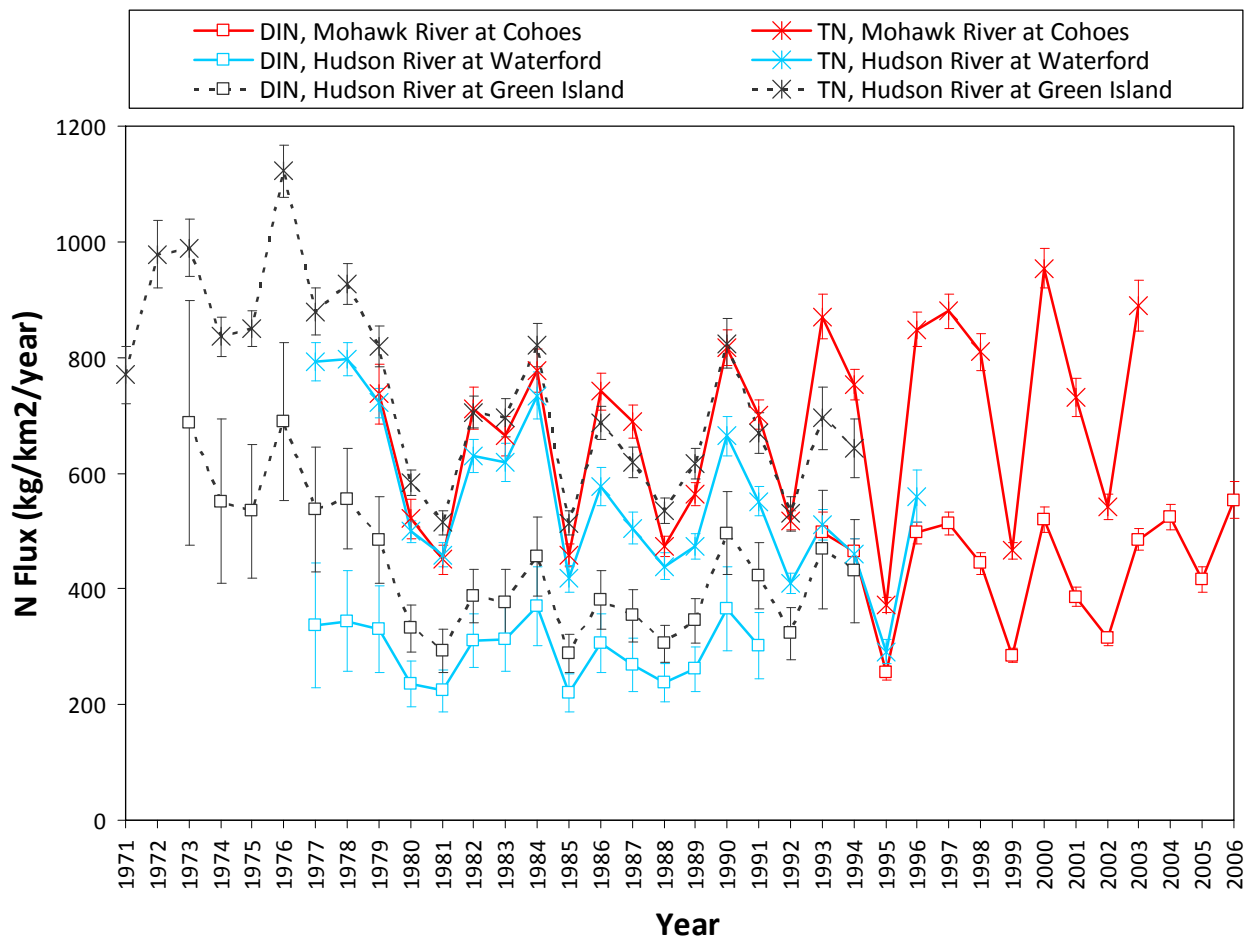
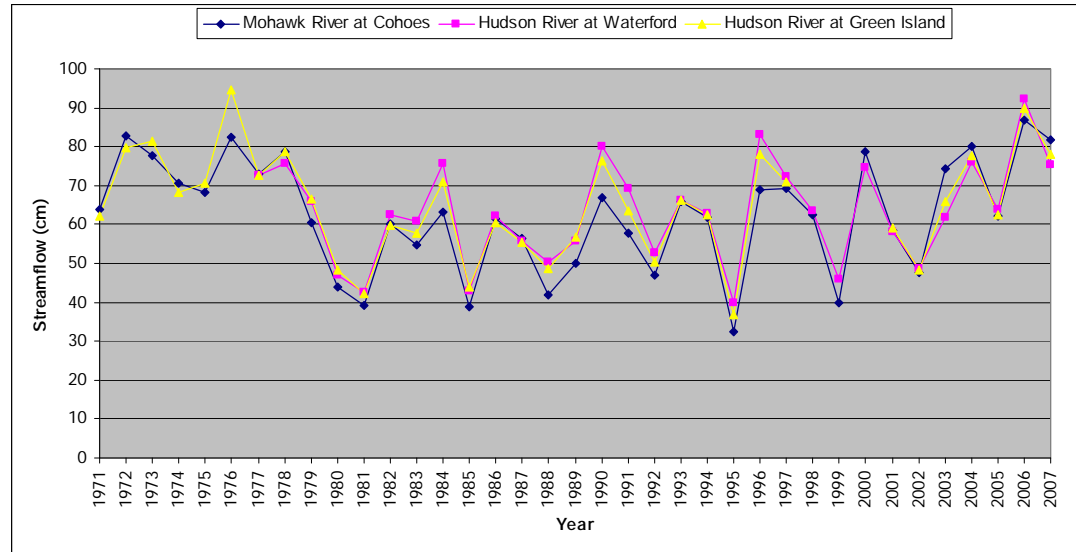


Figure 3. Interannual estimates of annual nitrogen fluxes made using the USGS Fluxmaster regression model and historical streamflow and nitrogen concentration measurements. Vertical bars indicate ± 1 standard error as generated by the Fluxmaster model.

Atmospheric Deposition Estimates for the Hudson/Mohawk

The atmospheric deposition component of NANI has been based on a combination of atmospheric model estimates and deposition network measurements. The state-of-the-art CMAQ model uses data on emissions of nitrogen pollution to the atmosphere over time and simulates advective transport through the atmosphere, chemical reactions within the atmosphere, and both wet and dry deposition, based on simulated meteorology, for the entire US, with an output spatial grid resolution of 36 km (12 km resolution is expected in 2008). The Chesapeake Bay Program intends to use the CMAQ model results as input for deposition estimates in the Bay Program Model in the future (Lewis Linker, US EPA, pers. comm.). Previously, the Bay Program has followed the same approach we have taken for our work at the scale of individual river basins in the northeastern US, and used NADP and CASTnet monitoring data to estimate deposition. This may have been a factor in underestimating the importance of deposition as a nitrogen source to Chesapeake Bay by almost 2-fold (15).

CMAQ estimates of atmospheric deposition (figure 4) show a range of deposition from low values in the forested, sparsely populated North, to very high values in the urbanized South. This gradient in part reflects the correlation between automotive emission sources and short-range atmospheric deposition. While atmospheric deposition is quantitatively small compared to some other watershed inputs at the watershed scale, it can dominate nitrogen inputs in regions of low population and little agriculture (e.g. the Adirondacks and other forested areas of the watershed). Higher resolution maps, currently available at a 12-km grid for 2002 (not shown) reveal the same pattern at the watershed scale. Future work in the region will compare field studies in the NYC metropolitan area to CMAQ estimates, thereby providing validation and testing for our collaborative work.

NANI calculator: Net Anthropogenic Nitrogen Inputs to the Hudson/Mohawk

The NANI calculator permits relatively rapid estimation of major nitrogen inputs from publicly available datasets in the United States (see <http://www.eeb.cornell.edu/biogeonanc/nani/nani.htm> for details). Figure 5 illustrates the variation of net anthropogenic nitrogen inputs across the hydrologic units of the Hudson watershed, estimated using the calculator. It is evident from the figures that there is a strong latitudinal gradient in NANI (figure 5a) and its constituents, corresponding in part to a gradient in population density. Food and feed inputs of nitrogen (5b) are strongly driven by the density of human and livestock populations. Atmospheric deposition of nitrogen (5c) is highest in the southernmost region of the watershed, dominated by the NYC metro area and lowest in the forest regions of the North, with relatively low densities of people and automobiles. Fertilizer (5d) and agricultural N fixation (not shown) are high in the intermediate latitudinal regions of the watershed, where agriculture predominates, and low in the urbanized and forested regions of the northern and southern ends of the watershed.

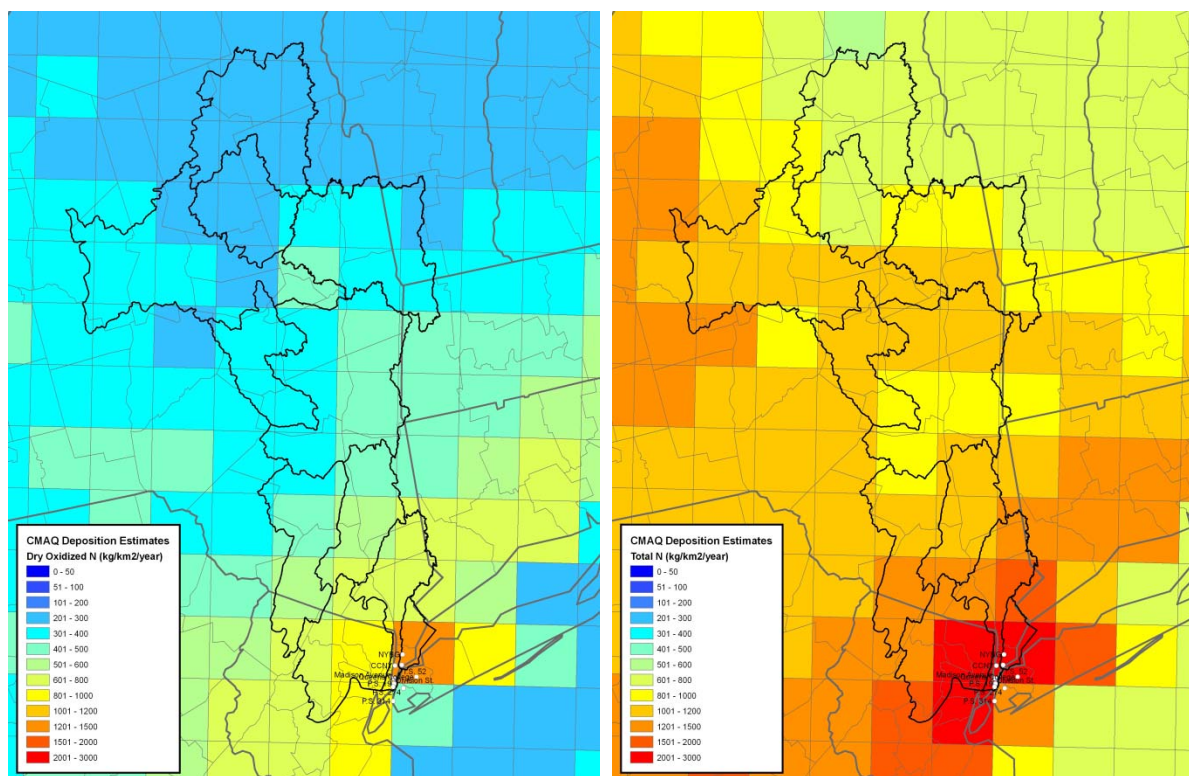
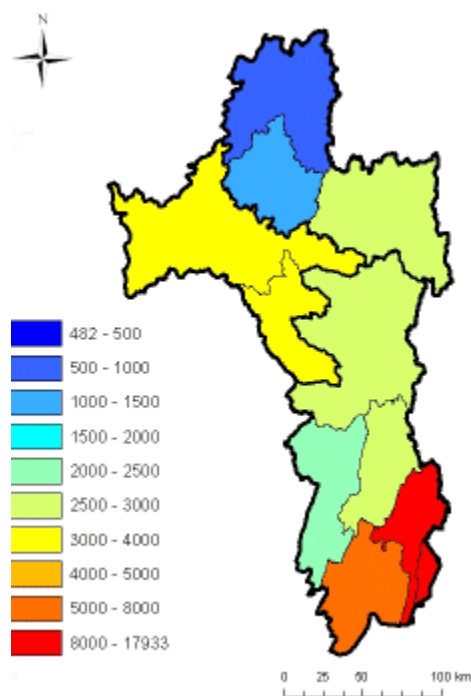
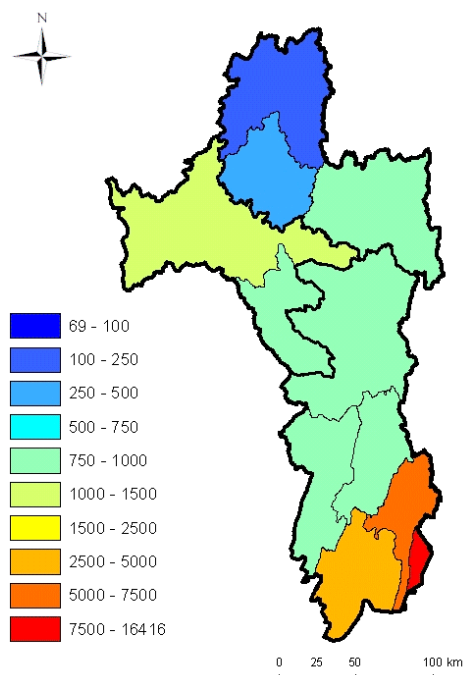


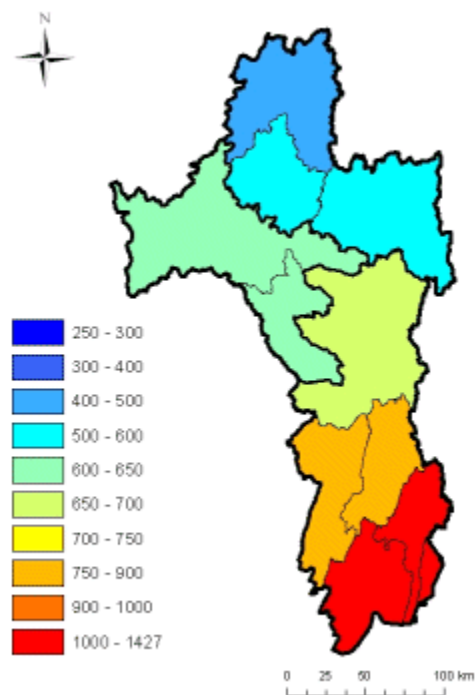
Figure 4. CMAQ model estimates of nitrogen deposition over the Hudson basin and surroundings at 36-km grid cell resolution. A) dry deposition of oxidized N species. B) Total (wet+dry) deposition of all nitrogen species. The model shows latitudinal gradients over the basin related to regional variation of sources, plus an intense area of deposition in the metropolitan New York area of the lower Hudson, indicating the effect of automobiles in high-density urban environments.



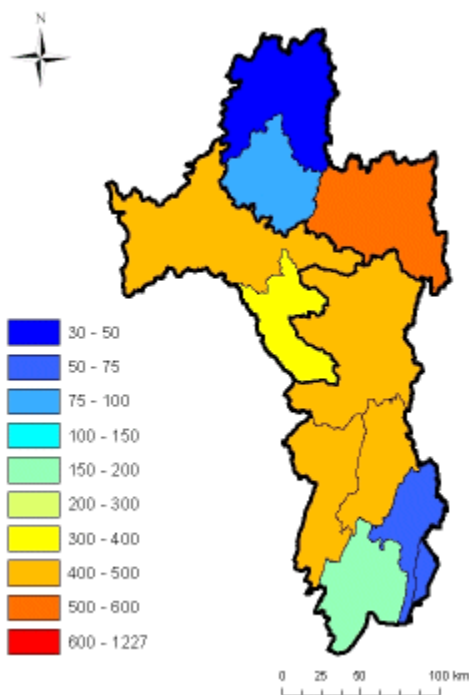
5.a) Overall net anthropogenic N inputs



5.b) Nitrogen in net food and feed imports



5.c) Atmospheric deposition of oxidized nitrogen



5.d) Nitrogen in fertilizer application

Figure 5. Some major nitrogen inputs to subbasins of the Hudson watershed. Food and feed input estimates (1b) derived from county level census and agricultural census data. Atmospheric deposition (1c) derived from EPA's CMAQ model estimates. Fertilizer N derived from county level data in Ruddy et al (2006). Bold lines delineate the three major subbasin boundaries (Upper Hudson, Mohawk, and Lower Hudson); light lines delineate major Hydrologic Units of the Hudson basin. Note different scales of N input on each map.

ReNuMa Model Summary

Modeling streamflow and nitrogen in large basins.

ReNuMa, a hydrologically-driven, quasi-empirical model designed to estimate nutrient fluxes at the scale of large watersheds (i.e., several thousand km²), is based on two lines of earlier work: GWLF, a lumped-parameter, watershed-scale hydrology, sediment, and nutrient transport model, and a variation of NANI. ReNuMa is quasi-empirical in that it makes no attempt to model detailed mechanisms of biogeochemical processes; most relationships in the model are based on empirical response functions and mass balance. It is a lumped-parameter model in that it does not deal with

spatially explicit details of watershed processes, but rather aggregates areas of similar land use/land cover into categories which can be modeled as independent sources of nutrients and runoff.

Estimates of nutrient inputs to the watershed are used to estimate runoff and groundwater concentrations following empirical response functions, and these are used together with calculated streamflows to estimate riverine N fluxes from the watershed. (Figure 6).

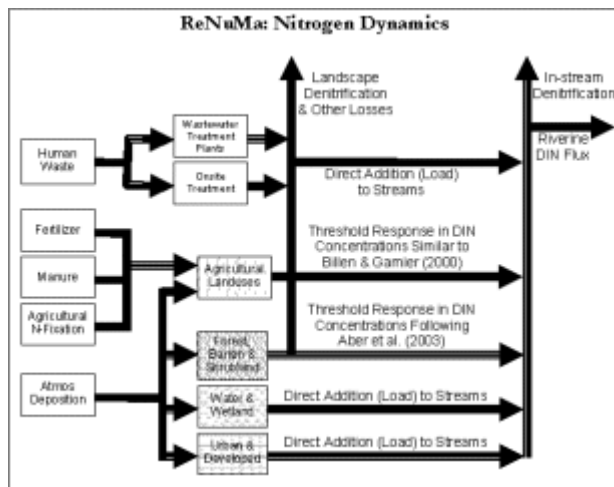


Figure 6. Diagram of ReNuMa nitrogen dynamics

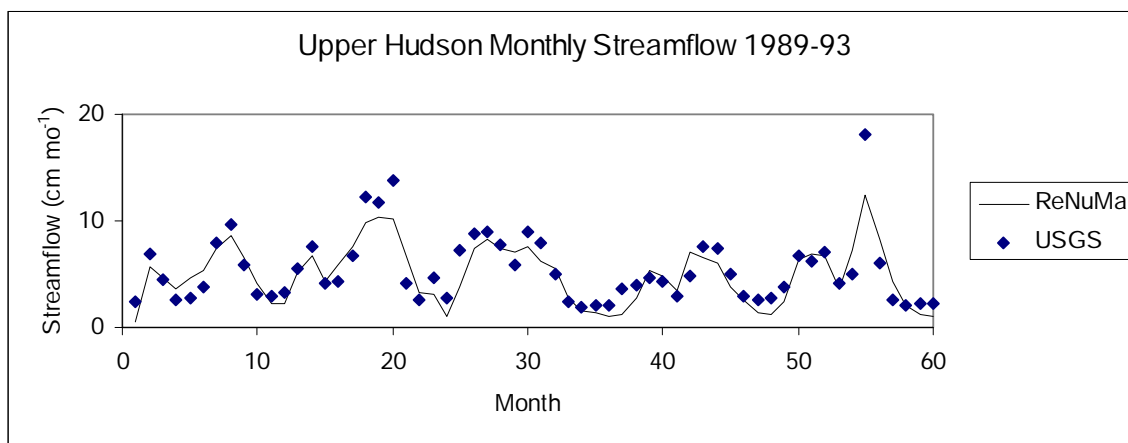
Watershed-scale nitrogen fluxes. ReNuMa was used to estimate streamflow nitrogen fluxes from major subwatersheds within the overall Hudson basin to the Hudson estuary. Streamflow and DIN flux could then be compared with USGS observations of streamflow at available gauging stations, and corresponding fluxmaster model estimates at these stations. As part of the parameterization of the ReNuMa model, estimates of the major components of net anthropogenic nitrogen inputs (NANI) were made for the entire Hudson River basin as well as for major sub-basins, including the Mohawk River basin, the upper Hudson River basin, and the combined watersheds of the lower Hudson (see previous section). The NANI method is used to assess the relative importance of the various inputs of nitrogen to regions and large river basins, including nitrogen in food and livestock feed, atmospheric deposition of nitrogen, fertilizer, and nitrogen fixation by crops, and to relate this to riverine fluxes of nitrogen from the watersheds. A variant of the NANI accounting approach is embedded in the ReNuMa model, together with response functions dependent on land use category. As a result, estimates can be made of the spatial and temporal variation of riverine N fluxes due to changes in both hydrological drivers (climate) and nitrogen drivers (human activities related to NANI and other processes; figure 7).

Over the five-year period (1989-93) simulated in the exercise shown, seasonal variation of ReNuMa estimates of streamflow are in good agreement with observations from both the Upper Hudson (measured at Waterford, NY) and the Mohawk (measured at Cohoes). A single monthly estimate of streamflow in 1993 appears to be significantly underestimated. The corresponding nitrogen flux estimates also show good seasonal agreement, with ReNuMa slightly underestimating peak seasonal monthly values, but reproducing seasonal trends quite well. (Discrepancies between

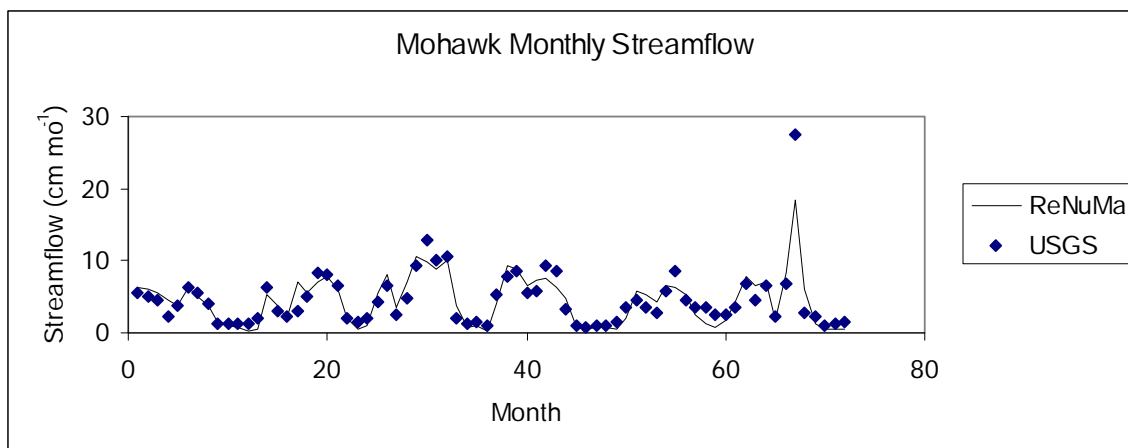
estimated and observed streamflows are propagated into errors in DIN flux, so that the underestimate of streamflow in 1993 results in a corresponding underestimate of DIN). The simulations indicate hydrology is a strong driver of temporal patterns of DIN flux.

A compelling reason to focus special attention on regional variations of N sources within the Hudson watershed is that it is evident that regional variations in impact exist. The Upper Hudson and Mohawk represent large forested and agricultural areas which are sources of most nutrients to the river. However, our recent work (funded by the Hudson River Foundation) shows that most (~60%) of the nitrogen entering the lower Hudson estuary originates in the NYC area. This is clearly shown by the relationship of total nitrogen concentrations and salinity in the lower Hudson estuary: they are related in a linear fashion, with consistently higher total nitrogen concentrations at greater salinities. Obviously, much of this nitrogen from the urban area is from sewage inputs, but we hypothesize the inputs from atmospheric deposition from local sources are a significant component of the NYC urban load. Wet deposition of nitrogen monitored at NY State DEC station 7094-06 at the New York Botanical Gardens. Deposition is high, averaging 7.8 kg N per hectare per year in recent years (<http://www.dec.state.ny.us/website/dar/baqs/acidrain/bgtrend.html>), or about twice the average for NY State.

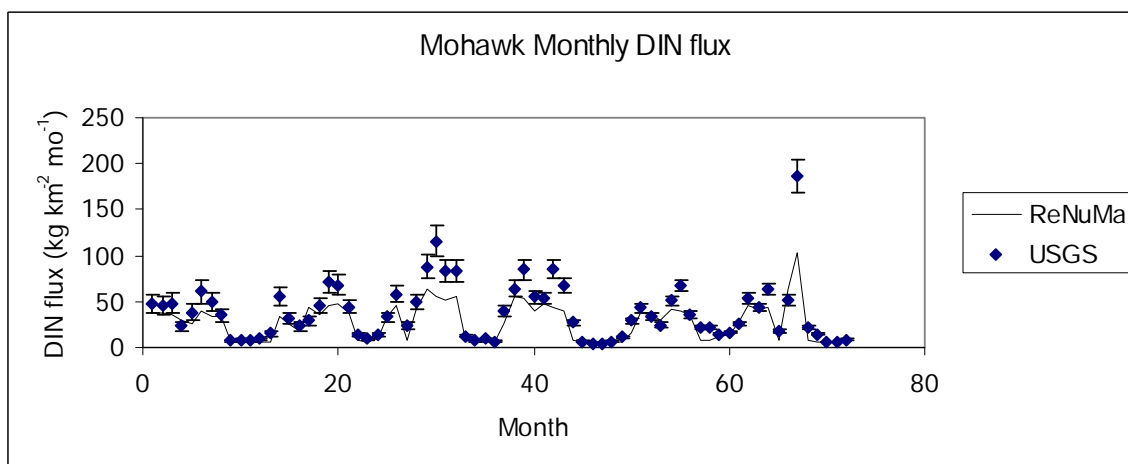
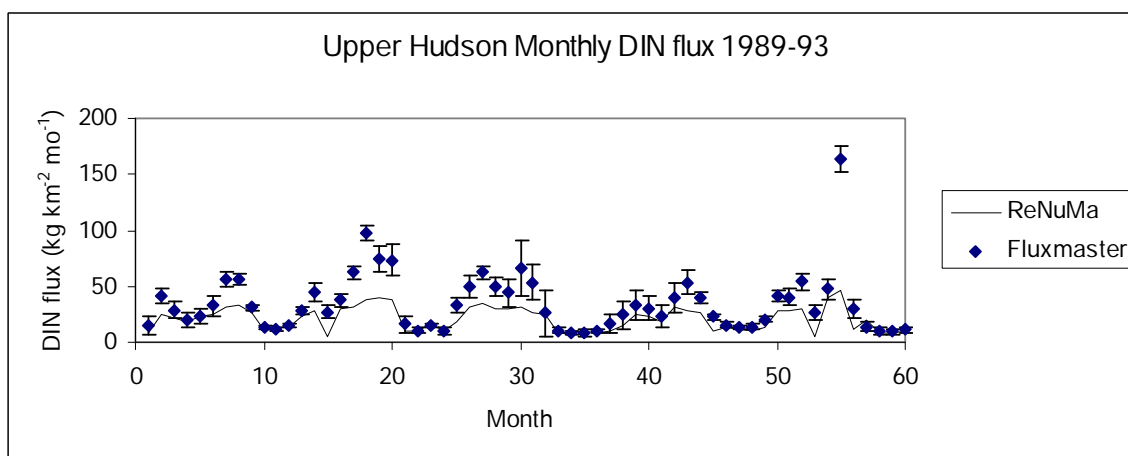
The general scarcity of dry deposition monitoring in the US makes estimation uncertain from measurements: dry deposition of particles and nitric acid is commonly estimated from statistical relationships between wet and dry deposition where both are measured. The CMAQ model should provide better estimates of the depositional component of load than previously available. Similar scarcity of streamflow and nutrient concentration data in the lower Hudson make validation of ReNuMa an ongoing challenge. In ongoing work, we will attempt to compile available NYDEP and other nutrient data to estimate nitrogen flux data for comparison with whole-watershed ReNuMa estimates of nitrogen flux in the Hudson.



7a



7b



7d
Figure 7. Comparisons between ReNuMa estimates and

observations of streamflow (7a,b) and dissolved inorganic nitrogen fluxes (7c,d) for the Upper Hudson and Mohawk watersheds.

STUDENT SUPPORT

No students were funded directly on this project. However, software developed in the course of the project has been used by students at SUNY-ESF in research leading to advanced degrees (K. Limburg, personal communication).

NOTABLE ACHIEVEMENTS (INCLUDING PUBLICATIONS AND PRESENTATIONS)

Publications

Howarth, R. W. 2008. Coastal nitrogen pollution: A review of sources and trends globally and regionally. *Harmful Algae*. 8:14-20.

Boyer E. W. & R. W. Howarth 2008. Nitrogen fluxes in rivers to the coastal oceans. Chapter 36, pp. 1565-1584, in: Capone DG, D Bronk, M Mulholland, and EJ Carpenter (eds.), *Nitrogen in the Marine Environment*, 2nd edition, Academic Press, San Diego, 1668pp.

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Swaney, D.P., D. Scavia, R.W. Howarth and R.M. Marino. 2008. Estuarine classification and response to nitrogen loading: Insights from simple ecological models, *Estuarine, Coastal and Shelf Science*. doi:10.1016/j.ecss.2007.09.013

Presentations

Poster Presentation: Estimating nitrogen fluxes from large watersheds with the Regional Nutrient Management Model (ReNuMa). B. Hong, D.P. Swaney, and R. W. Howarth. Presented at the 4th IGBP Congress, Cape Town, South Africa, May 5-9, 2008.

Poster Presentation: Estimating Nitrogen Fluxes from 16 Northeastern US Watersheds with the Regional Nutrient Management Model (ReNuMa). B. Hong, D. P. Swaney and R. W. Howarth. Presented at the Chesapeake Modelling Symposium, Annapolis, MD. May 12-14, 2008.

Oral Presentation: Nutrient Accounting in Coastal Waters and Watersheds: Linkages and Applications. D.P. Swaney. Presented at the ASLO Aquatic Sciences meeting, Nice, France. January 25-30, 2009.

SYNERGISTIC ACTIVITIES (OTHER OPPORTUNITIES & COLLABORATIONS THAT WERE ENABLED BY THE GRANT)

Several collaborations and synergistic activities have been supported by this grant, including:

Collaboration with the NOAA/EPA CMAQ atmospheric deposition modeling team. Over the last year or so, researchers in the project have corresponded regularly by email and exchanged datasets. Project

personnel met with Robin Dennis and Donna Schwede in late October, 2008, to discuss modeling details and specific data needs. We plan to continue collaborating, in part to examine details of urban atmospheric nitrogen deposition and its consequences for the lower Hudson.

Participation in Cornell's agricultural ecosystems program. The Cornell Agricultural Ecosystems Program (AEP) currently focuses on the Susquehanna watershed and its impact on Chesapeake Bay. Because similar issues affect much of the Hudson Basin, tools developed for use in the Hudson apply to the Susquehanna and vice versa. Specifically, the ReNuMa model, which is being applied in the Hudson with support from the USGS/WRI is also being used in the Susquehanna. Of major interest is the interplay between modeling and field studies at different scales, and the possibility "scaling up" small scale investigations to watershed scale research using the ReNuMa model.

Collaboration with NOAA CHRP project.

Ongoing work funded by a NOAA grant in collaboration with researchers at the University of Michigan facilitates further development of NANI methodology and the ReNuMa model in a context extending beyond the Hudson. In addition, our research should enable a better understanding of the coupling between watershed nutrient fluxes and the response of estuarine and other coastal waters, including the Hudson River estuary.

Ongoing research funded by USGS/NYSWRI/NYDEC.

Our ongoing work funded by NYSWRI will continue to investigate processes within the Hudson/Mohawk watershed. Two related projects will follow on from this work. The first is aimed at examining sources and sinks of silicon within the watershed, and the relationships between this nutrient and others, especially in regard to eutrophication and diatom abundance in the Hudson and its estuary. The second relates to changes in infrastructure in the watershed, including dams and impervious surfaces, and their effects on hydrologic and biogeochemical processes. Together with our current and ongoing research on nitrogen sources, we hope that this work will provide a more complete picture of the interactions between hydrology, nutrients and riverine/estuarine ecology of the Hudson.

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Appendices

Appendix 1. Procedure for downloading daily weather data from regional weather station files

To access multiple, individual weather station data from the NCDC website, open a web browser and navigate to: <http://cdo.ncdc.noaa.gov/CDO/dataproduct>. Then follow the directions in the following figures. The result will be an ftp link containing the desired data, which can be downloaded from the website.

A few considerations for choosing the number of stations to download:

The files are .txt files, which can be imported into excel. Excel (2003 and earlier) has a row limit of ~65000...this corresponds to a dozen or so sites worth of data, assuming 6 or so parameters selected, and an “average” period of record. Longer period sites and more parameters chosen will increase the number of rows.

The format of output is as follows: for any month in the record, all daily values of a parameter are output on a single line, so the number of columns depends on the number of days of the month. Each parameter chosen is reported on a separate line. If a parameter is missing for an entire month, the line for the parameter may not be reported; partially missing data will include a line with the parameter code and other data. Details of file format and codes can be found in the file: soddoc.txt which is included in each download.

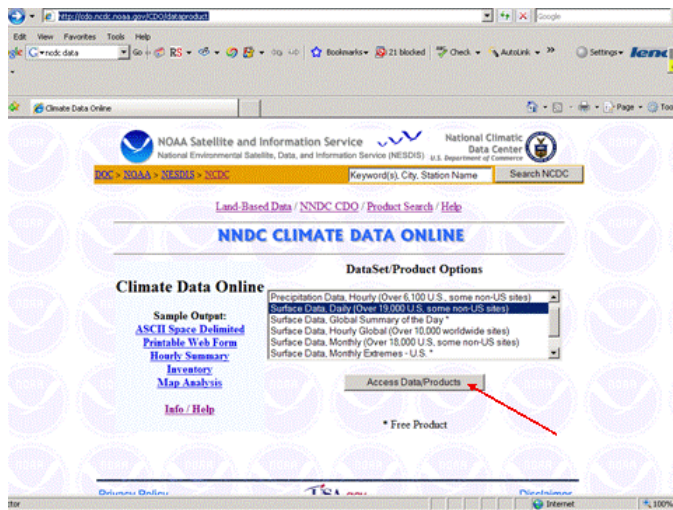


Figure a1. NCDC climate data selection. First choose surface daily data, and press “access data products”

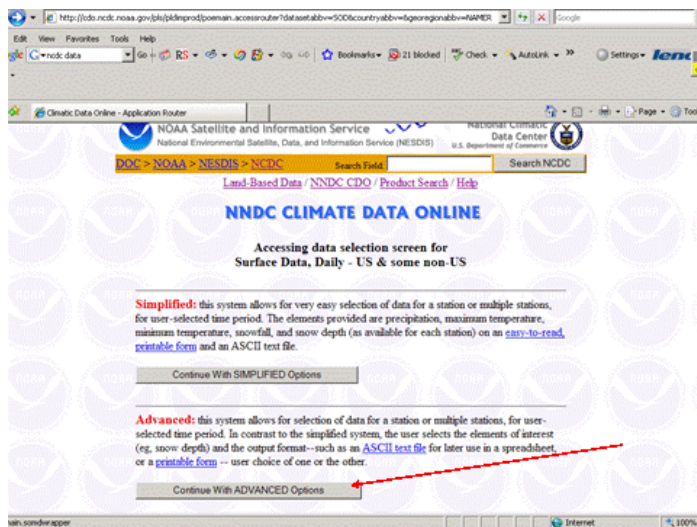


Figure a2. Select “continue with advanced options” to permit selection of multiple stations

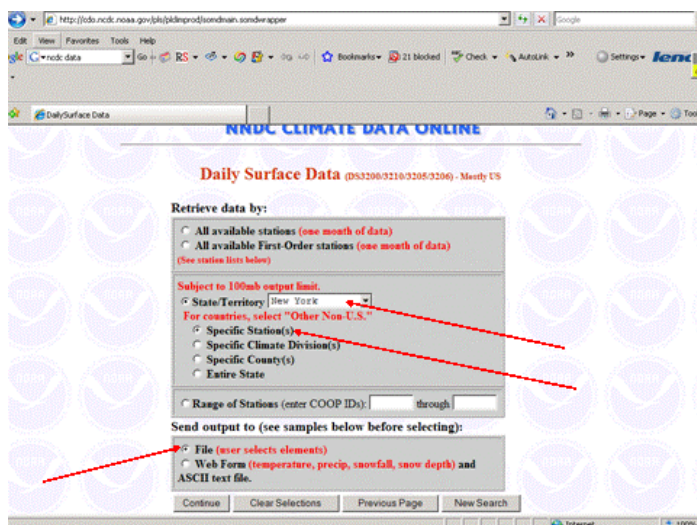


Figure a3. Select state and specific stations, and file output

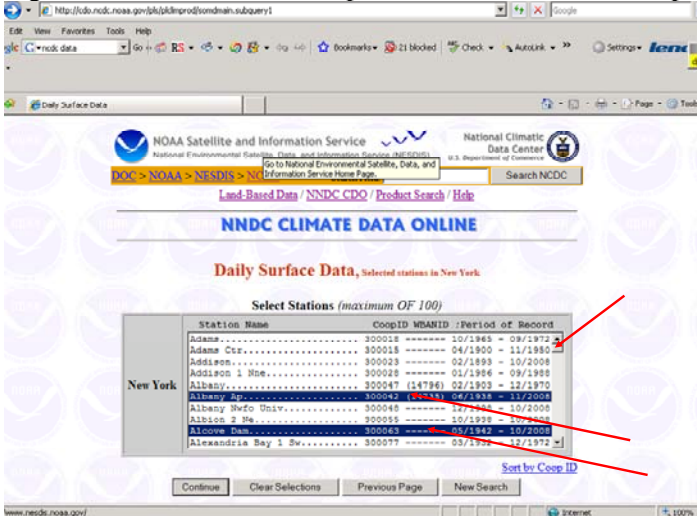


Figure a4. Choose desired stations from list (holding down ctrl key to choose more than 1 station)

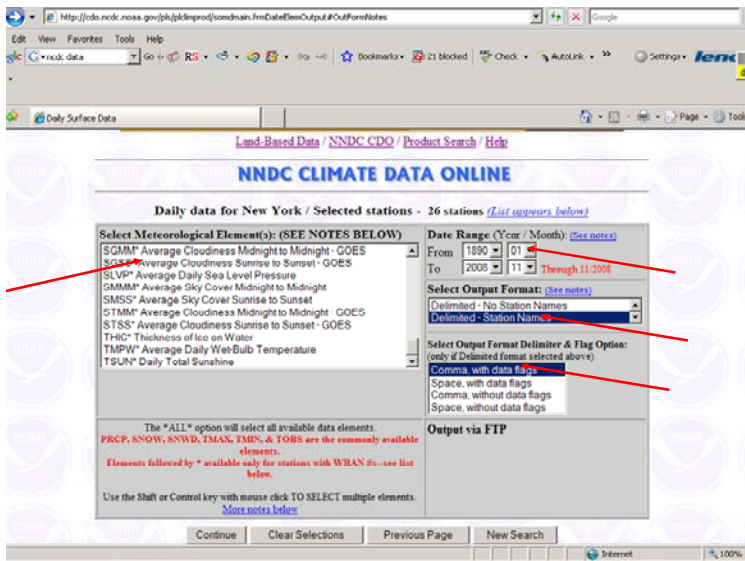


Figure a5. Choose desired time period desired parameters (holding down ctrl key to choose more than 1 parameter), and output option (comma delimited text)

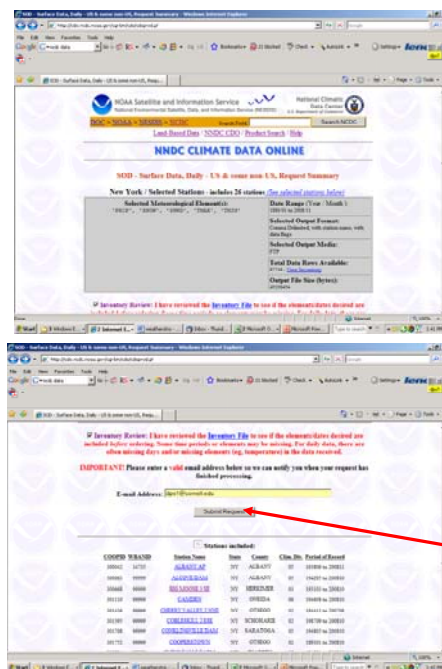


Figure a6. Verify list of parameters chosen, and enter email address for notification of dataset processing

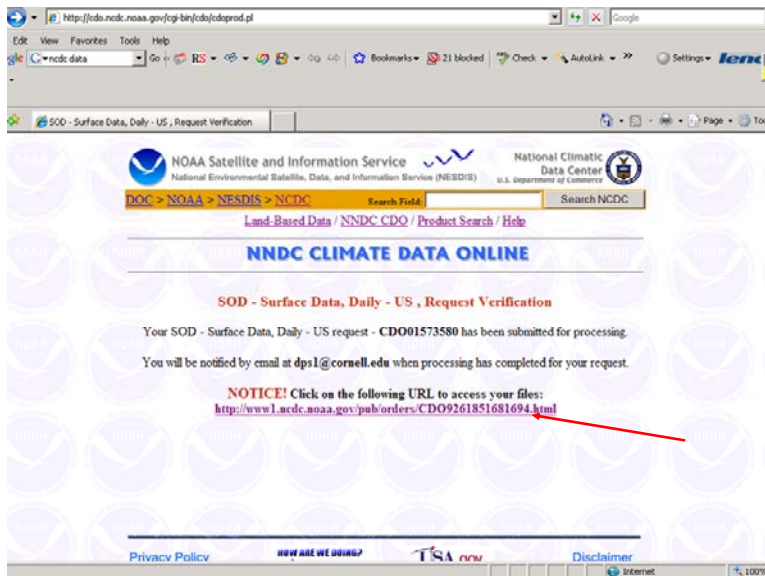


Figure a7. If the processing is completed quickly enough, the user can navigate directly to the specified URL to access the processed weather data file. Otherwise, the URL will be emailed to the specified address, whereupon the user can navigate to the website and download the data.

After the data are downloaded, they can be opened with (imported into) MS excel. An excel macro for processing the daily data and creating separate worksheets for each weather station follows below in Appendix 2.

Appendix 2. Excel macro for processing downloaded NCDC weather data

The following macros will process downloaded data in NCDC format into separate worksheets containing individual parameters in separate columns, (daily temperature (C) and precipitation (cm). The spreadsheet requires a separate worksheet containing downloaded data, and a separate worksheet containing the names and coopids of each station to be processed (see attached Excel file).

Sub reorder()

```
Dim vlabels(), stnid(), stnname$, wval(), dt(), gap As Long
' open worksheet with the list of station coopids and names, and place in arrays
Worksheets("stations").Activate
Worksheets("stations").Cells(4, 1).Select
startreportyr = Cells(2, 2)
startreportmo = Cells(2, 3)
endreportyr = Cells(3, 2)
endreportmo = Cells(3, 3)
Range(Selection, Selection.End(xlDown)).Select
numrows = Selection.Rows.Count
ReDim stnid(numrows - 1), stnname(numrows - 1)
For i = 1 To numrows - 1
    stnid(i) = Cells(i + 4, 1)
    stnname$(i) = Cells(i + 4, 2)
Next i
numstns = numrows - 1
finalname = stnname(numstns)
```



```
' open worksheet with downloaded data, loop through each station, and place desired weather data in  
separate worksheets
```

```
Worksheets("downloadeddata").Activate  
Worksheets("downloadeddata").Cells(1, 1).Select
```

```
Range(Selection, Selection.End(xlDown)).Select  
Range(Selection, Selection.End(xlToRight)).Select  
numrows = Selection.Rows.Count  
numcols = Selection.Columns.Count  
ReDim vlabels(numcols)
```

```
' determine which column holds the coopid and other codes code
```

```
For i = 1 To numcols  
vlabels(i) = Cells(1, i)  
Next i
```

```
' determine which column holds the coopid and other codes code
```

```
val1 = getcol("COOPID", 1, numcols, 1)  
If val1 = -9999 Then  
Stop  
Else  
icoop = val1  
End If  
val1 = getcol("ELEM", 1, numcols, 1)  
If val1 = -9999 Then  
Stop  
Else  
iwcol = val1  
End If  
val1 = getcol("YEARMO", 1, numcols, 1)  
If val1 = -9999 Then  
Stop  
Else  
iyrmo = val1  
End If
```

```
For istn = 1 To numstns  
coopid = stnid(istn)  
ReDim wval(100000, 3), dt(100000, 3)  
j = 0  
kcount = 0
```

```
started = False
```

```
Worksheets("downloadeddata").Select
```

```
newdate = -10000  
jstart = 0  
Do  
j = j + 1  
If Cells(j, icoop) = coopid Then
```

```

    started = True
    jstart = jstart + 1
    yr = Val(Left(Cells(j, iyrmo), 4))
    mo = Val(Right(Cells(j, iyrmo), 2))
    newdate2 = DateSerial(year(newdate), Month(newdate), lenmnth(year(newdate), Month(newdate)))
    modays = lenmnth(yr, mo)
    If DateSerial(yr, mo, 1) = newdate Then newdt = False Else newdt = True
    If newdt And jstart > 1 Then
        gap = DateSerial(yr, mo, 1) - newdate2 - 1
        If gap > 0 Then ' if gaps exist due to missing months, fill with missing data codes
        For jg = 1 To gap
            kcount = kcount + 1
            dt(kcount, 1) = year(newdate2 + jg)
            dt(kcount, 2) = Month(newdate2 + jg)
            dt(kcount, 3) = Day(newdate2 + jg)
            For iiii = 1 To 3: wval(kcount, iiii) = -9999: Next iiii
        Next jg
    End If
End If

newdate = DateSerial(yr, mo, 1)
iwcod = 0

If Cells(j, iwcol) = "PRCP" Then iwcod = 1
If Cells(j, iwcol) = "TMAX" Then iwcod = 2
If Cells(j, iwcol) = "TMIN" Then iwcod = 3
If iwcod > 0 Then
    For nday = 1 To modays

        If newdt Then
            kcount = kcount + 1
            dt(kcount, 1) = yr
            dt(kcount, 2) = mo
            dt(kcount, 3) = nday
            For kkkk = 1 To 3: wval(kcount, kkkk) = -9999: Next kkkk ' note that the missing data code in the
data is -99999
        End If 'newdt

        If IsNumeric(Cells(j, 6 + 4 * nday)) Then
            If newdt Then wval(kcount, iwcod) = Cells(j, 6 + 4 * nday) Else wval(kcount - modays + nday,
iwcod) = Cells(j, 6 + 4 * nday)
        ' Else
        ' If newdt Then wval(kcount, iwcod) = -9999 Else wval(kcount - modays + nday) = -9999
        End If

    Next nday
End If ' iwcod > 0

End If ' started
Loop Until j > numrows
If started Then

```

```

Call createworksheet(stnname$(istn))
kc2 = 0
Worksheets(stnname$(istn)).Select
'write column headings
Worksheets(stnname$(istn)).Cells(1, 1) = "year"
Worksheets(stnname$(istn)).Cells(1, 2) = "month"
Worksheets(stnname$(istn)).Cells(1, 3) = "day of month"
Worksheets(stnname$(istn)).Cells(1, 4) = "daycount"
Worksheets(stnname$(istn)).Cells(1, 5) = "raw precip - hundredths of inches"
Worksheets(stnname$(istn)).Cells(1, 6) = "daycount"
Worksheets(stnname$(istn)).Cells(1, 7) = "raw tmax F"
Worksheets(stnname$(istn)).Cells(1, 9) = "raw tmin F"
Worksheets(stnname$(istn)).Cells(1, 11) = "date"
Worksheets(stnname$(istn)).Cells(1, 12) = "precip cm"
Worksheets(stnname$(istn)).Cells(1, 13) = "tavg C"
Worksheets(stnname$(istn)).Cells(1, 10) = "continuity check (should =1; difference in sequential dates)"

    For jjj = 1 To kcount
        date1 = DateSerial(dt(jjj, 1), dt(jjj, 2), dt(jjj, 3))
        If date1 >= DateSerial(startreportyr, startreportmo, 1) And date1 <= DateSerial(endreportyr,
endreportmo, lenmnth(endreportyr, endreportmo)) Then
            kc2 = kc2 + 1
            For j2 = 1 To 3
                Worksheets(stnname$(istn)).Cells(kc2 + 1, j2) = dt(jjj, j2)
                Worksheets(stnname$(istn)).Cells(kc2 + 1, 2 * j2 + 2) = jjj
                Worksheets(stnname$(istn)).Cells(kc2 + 1, 2 * j2 + 3) = wval(jjj, j2)

            Next j2

            If dt(jjj, 1) >= 1900 Then Worksheets(stnname$(istn)).Cells(kc2 + 1, 11) = date1

            pcp = wval(jjj, 1)
            If pcp > -9999 Then pcp = pcp * 0.0254 Else pcp = -9999
            Worksheets(stnname$(istn)).Cells(kc2 + 1, 12) = pcp
            tmn = wval(jjj, 3)
            tmx = wval(jjj, 2)
            If tmx > -9999 And tmn > -9999 Then tavg = ((tmx + tmn) / 2# - 32) * 5# / 9# Else tavg = -9999
            Worksheets(stnname$(istn)).Cells(kc2 + 1, 13) = tavg
            If kc2 > 1 Then Worksheets(stnname$(istn)).Cells(kc2 + 1, 10) =
Worksheets(stnname$(istn)).Cells(kc2 + 1, 11) - Worksheets(stnname$(istn)).Cells(kc2, 11)
            End If
            Next jjj
        End If
    Next istn
End Sub 'reorder

```

Function lenmnth(yr, monum) ' returns the number of days of month monum in the specified year
(monum runs from from 1 to 12 beginning in Jan)
dd = DateSerial(yr, monum + 1, 1)
lenmnth = Day(dd - 1)

'if yr is divisible by 4, its a leapyear, unless divisible by 100, in which it isnt, except if divisible by 400 in which case it is

End Function ' 1900 is not a leapyear but 2000 is a leapyear

Sub createworksheet(SheetName\$)

st1\$ = " worksheet already exists. "

Do While SheetExists(SheetName\$) Or Len(SheetName\$) = 0

sheetname2\$ = getstrg\$(SheetName\$ & st1\$ & "New worksheet name?", SheetName\$)

If sheetname2\$ = SheetName\$ And Len(sheetname2\$) > 0 Then Exit Do

If Len(sheetname2\$) > 0 Then SheetName\$ = sheetname2\$

Loop

If SheetExists(SheetName\$) Then ' if you elect to use the existing worksheet, clear it before overwriting

Call clearworksheet(SheetName\$)

Else ' otherwise, create a new one

Worksheets.Add after:=Sheets(1)

Sheets(2).Name = SheetName\$

Worksheets(SheetName\$).Activate

End If

End Sub

Sub clearworksheet(worksheetname\$)

If SheetExists(worksheetname\$) Then Worksheets(worksheetname\$).Cells.Clear

End Sub

Function getstrg\$(promptstr\$, defaultstr\$)

Dim Title, MyValue

Title = "Enter a name" ' Set title.

line2 = ""

If (Len(defaultstr\$) > 0) Then line2 = "(default = " & defaultstr\$ & ")"

' Display message, title, and default value.

MyValue = InputBox(promptstr\$ & Chr(13) & Chr(13) & line2, Title, defaultstr\$)

getstrg\$ = MyValue

End Function

Public Function SheetExists(sname) As Boolean

' returns true if sheet exists (Walkenbach, 1999)

' note that this code only works if "break on unhandled errors" option is set in Tools>Options>General tab of visual basic

Dim x As Object

On Error Resume Next

z = ActiveWorkbook.Name

Set x = ActiveWorkbook.Sheets(sname)

If Err = 0 Then SheetExists = True Else SheetExists = False

End Function

Function getcol(str\$, startcol, endcol, row)

j = 0

```
For i = startcol To endcol
j = j + 1
If Cells(row, i) = str$ Then
getcol = j
GoTo 999
End If
Next i
getcol = -9999
999
End Function

Function testdt(yr, mo, d)
testdt = DateSerial(yr, mo, d)
End Function
```

Best management practices for managing stormwater runoff from developing areas in the Hudson River Valley

Basic Information

Title:	Best management practices for managing stormwater runoff from developing areas in the Hudson River Valley
Project Number:	2008NY104B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	22
Research Category:	Water Quality
Focus Category:	Non Point Pollution, Surface Water, Management and Planning
Descriptors:	None
Principal Investigators:	Tammo Steenhuis, Larry D Geohring, Brian Richards

Publication

TITLE: BEST MANAGEMENT PRACTICES FOR MANAGING STORMWATER RUNOFF FROM DEVELOPING AREAS IN THE HUDSON RIVER VALLEY

DURATION: March 1, 2008 - February 28, 2009

FEDERAL FUNDS REQUESTED: \$ 19,000

NON-FEDERAL FUNDS: \$ 28,500

INVESTIGATORS: Tammo S. Steenhuis, Larry D. Geohring, Zachary M. Easton, and Brian K. Richards, Department of Biological and Environmental Engineering, Cornell University

COOPERATOR: Kevin Sumner, Orange County Soil & Water Conservation District

CONGRESSIONAL DISTRICT: NY 22

PROBLEM STATEMENT AND RESEARCH OBJECTIVES

As documented in the *Hudson River Estuary: Report on 10 Years of Progress*, great strides have been made to “remove or remediate pollutants and their sources.” Consequently, the health of the Hudson River system is improving. However, new urban and suburban developments in the lower parts of the Hudson River basin – including the Walkill River watershed in Orange County – threaten this trend of declining pollution levels because development typically contributes to increased stormwater-related loadings. The management and treatment of stormwater runoff in urbanized and developing areas with substantial impermeable surface coverage presents a major challenge. Increasing quantities of runoff are generated from impermeable surfaces (roofs and pavement), yet the number of locations for adequate runoff storage and treatment are diminished as development proceeds. There are wide varieties of best management practices (BMPs) available to help manage storm water runoff. Structural BMPs include retention basins, rain gardens, filter strips, and devices to remove oil and grease from runoff, while non-structural BMP’s involve operational and management techniques that can limit adverse impacts of stormwater. As noted by cooperator Kevin Sumner of the Orange County Soil & Water Conservation District, developments typically are required only to implement a single BMP as part of the permitting process. Thus, preventing any potential adverse effects of development on stormwater-related loadings depends on the continued effectiveness of the selected BMP. One of the most promising BMPs is rain gardens. There is still a significant need for focused research on the actual in-field effectiveness of commercially-implemented practices for load reduction of sediments and nutrients.

The overall goal of our research was to define pollution to its source. Specifically for this project, we were interested in defining the potential reduction in pollution potential by BMPs specifically the study of rain gardens in developing areas in the lower Hudson Valley (Orange County) and in upstate New York (Village of Skaneateles and Lansing).

Specifically, we continued with project activities that were started during 2007:

- 1) Monitored four stormwater BMPs for a number of stormwater events; Inflow and outflow concentrations were measured during rainfall events
- 2) Improved design criteria for urban and suburban BMP's and developed recommendations for managing these BMP's in the Lower Hudson basin based as an alternative to treat water runoff from storms.

METHODOLOGY

The research was carried out in upstate New York in the villages of Skaneateles, Lansing, and in the village of Walden, NY. Walden is located in Orange County which is seeing significant development and have a number of opportunities for monitoring effectiveness of BMPs. Orange County has a wide range of soil and hydrologic conditions where development is occurring, ranging from undulating landscapes on glacial till to sandy soils, with karst aquifers.

Project Objective 1: The work proposed for Objective 1 involved sampling of surface and ground water for water quality purposes based on cooperative efforts with personnel of the Orange County Soil Water Conservation District. Kevin Sumner (District Manager) had advised regarding site selection and cooperated in sampling.

Site 1: The selected site 1 was located in the village of Walden, NY. Site 1 was a rain garden designed to intercept street runoff before it enters the river. The site was fully instrumented and functioning and by mid summer of 2008 a couple of automatic water sampler instruments were installed in the monitoring rain garden to collect water samples along rainfall events. One automatic water sampler unit was installed for sampling a culvert that collects pavement runoff. This culvert discharges the collected pavement runoff directly in to the rain garden. The second automatic water sampler was installed for sampling groundwater in a piezometer placed within the rain garden. The sampling interval time was defined base on previous examination of the weather forecast, then the automatic water samplers units were setup for sampling intervals covering the entire rainstorm. Additionally sampling of pre- and post-rainstorms was performed at five sampling sites which were pavement runoff in culvert structure, a well penetrating to the bottom of the rain garden (depth groundwater piezometer), a second well down gradient from the garden and above a nearby stream (shallow groundwater piezometer), stream flow in the nearby river and rainfall. Additional work included an elevation survey, and installation of an inflow capacitance probe, two wells to measure ground water levels directly below rain garden and next to the nearby river, a sampling structure for grab water samples, and a tipping bucket rain gauge.

Sites 2 and 3 were located in the village of Lansing and Skaneateles in upstate NY respectively. Site 2 in which a stormwater BMP was implemented and surface and subsurface water was only monitored during the occurrence of rainfall events. In this rain garden, five different grab sampling points were identified. They were rainfall, roof runoff, pavement runoff, subsurface flow within the rain garden, and stream flow. The input's source was only pavement runoff (and rainfall), and the whole input volume was infiltrated within the rain garden without any flow coming out of the rain garden but infiltration.

Monitoring site 3 located in the village of Skaneateles, NY had two monitored stormwater BMPs. The input source for these two rain gardens was roof runoff and rainfall. During the first half of 2008 year, grab water samples were collected on a regular basis during rainfall storms. By midsummer after some modifications were completed at one of the rain gardens, collecting plastic bottles were added to the sampling instruments to be sure that water samples were collected for all sampling points without missing any sampling point due to late arrival during the rainfall storms. There were five sampling points identified for each rain garden: rainfall, roof runoff, pavement runoff, subsurface flow within the rain garden and stream flow. Sampling of the rain gardens continued on a regular basis during rainfall events for the rest of 2008.

All water samples were analyzed for pH, nitrate, dissolved P, bromide, chloride, sulfate, metals (Fe, Mn, P, Pb, Zn, Cu, and Cd), and dissolved organic carbon (DOC). The sample collection, handling, and analysis utilized the standard protocols for water as per the US-EPA methods. For rain garden 1 located in Orange County, the pH measurement was done on site, as was filtration of the samples by the project personnel in collaboration with the Orange County Soil and Water District. Samples were immediately transported in cooled containers to Cornell University where they were analyzed. For sites 2 and 3, water samples were collected and transported in cooled containers to Cornell University where they analyzed as well.

Project Objective 2: This research phase is being carried out in cooperation with Dr. Elliot Schneiderman, Director of Watershed Modeling with NYCDEP. Dr Schneiderman is an expert in modeling and has adapted the GWLF model (Schneiderman et al. 2006) to include runoff generated from variable source areas and is now being called the Variable Source Loading Function (VSLF). The model is appropriate to use in Orange County with its extensive wetlands areas. Our findings are currently being incorporated into improved engineering designs for the application of treating urban stormwater runoff. We will continue to analyze the field effectiveness of each BMP based on the observed data as well as on expected BMP benefits based on modeling results with VSLF. This analysis is being done in the context of how the design of this type of pond and infiltration system can be improved or expanded to other areas where urban storm water management is necessary. Dr. Zachary Easton has started and will continue to model “expected” and actual post-development conditions. VSLF uses maps (such as a digital elevation map, land use map, and soils data) and precipitation data. These assessments are being communicated to the local Soil & Water Conservation district and to state-level Natural Resource Conservation Service (NRCS) conservation engineers. We plan the publishing of results in academic and practitioner-oriented outlets.

PRINCIPAL FINDINGS AND SIGNIFICANCE

In this project, water quality entering and leaving commercially-implemented stormwater BMPs (rain gardens) in residential sites was monitored. Monitoring at these locations includes the inflow and outflow points as well as piezometers that tap subsurface flow out of the gardens. Single independent rainstorms were monitored over the course of the rainfall events (from beginning to end), as well as single grab samples were taken during rainstorm events. An outstanding example of a long duration rainstorm is reported to the Orange County rain garden. During September 6 and 7, 2008 a rainstorm was monitored for 22 hours with one hour interval

samples in which 51 mm of precipitation were observed. Fig. 1 shows a concentration time plot of the inflow (Culv) and within-stormwater BMPs (DW) quality of dissolved metals to the Orange County rain garden fed by a residential area and a school parking lot. The variation in analysis concentrations is the result of varying storm intensity. By the end of the storm, a considerable increase in P and Fe inflow was observed which could be the result of accumulated wash off. However, there was not an observed response in the within- BMP monitored well for the same metals (P DW and Fe DW) indicating an initial good performance of the rain garden retaining pollutants. The analyses not shown are at non-detectable levels.

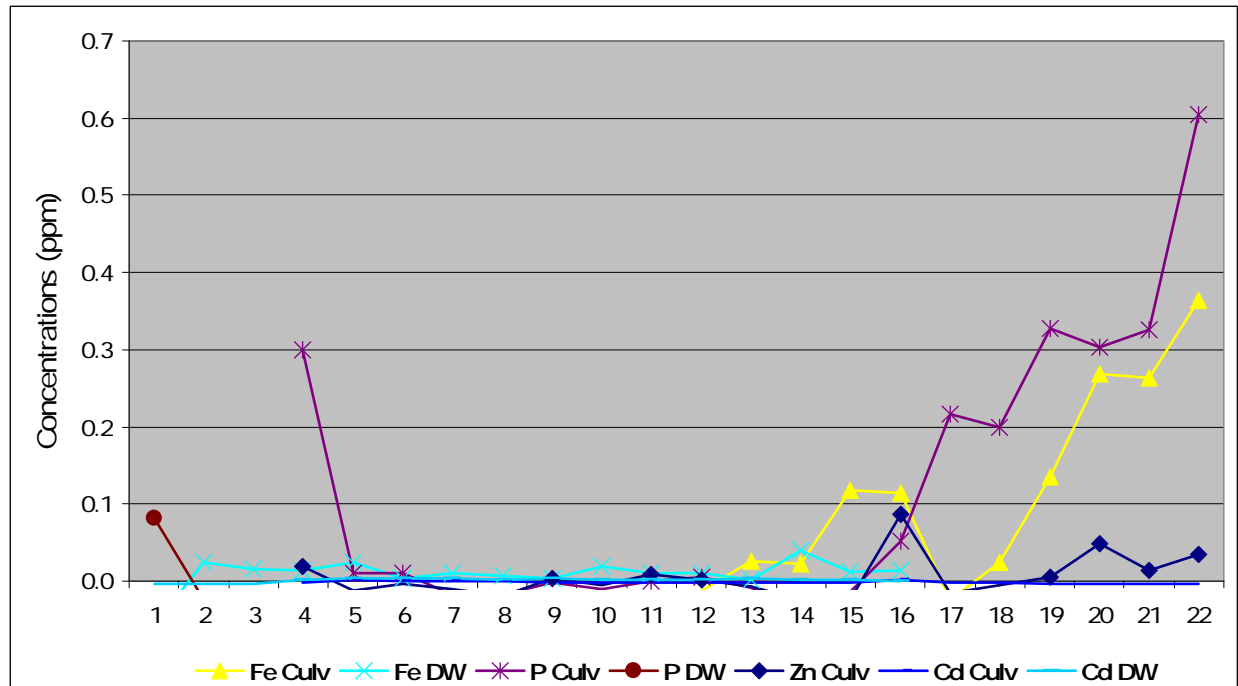


Figure 1. Inflow (Culv) and within- stormwater BMPs (DW) quality of dissolved metals to the Orange County suburban rain garden during a long storm on Sep. 6 and 7, 2008. Culv: culvert which is the inflow sampling structure and DW: deep well within the BMP or rain garden.

Similar to P and Fe inflow concentrations, DOC and sulfate inflow concentrations had comparable behaviors with a tendency of increasing concentrations as the end of the rainfall storm was approached (Fig. 2). Inflow and within-BMP nitrate concentrations were similar with an average inflow and within-BMP concentration of 0.2 mg/l and 0.1 mg/l respectively. These observed within-BMP nitrate concentrations indicate that the rain garden may not have a potential concern in terms of nitrate quality and show a good performance of the rain garden.

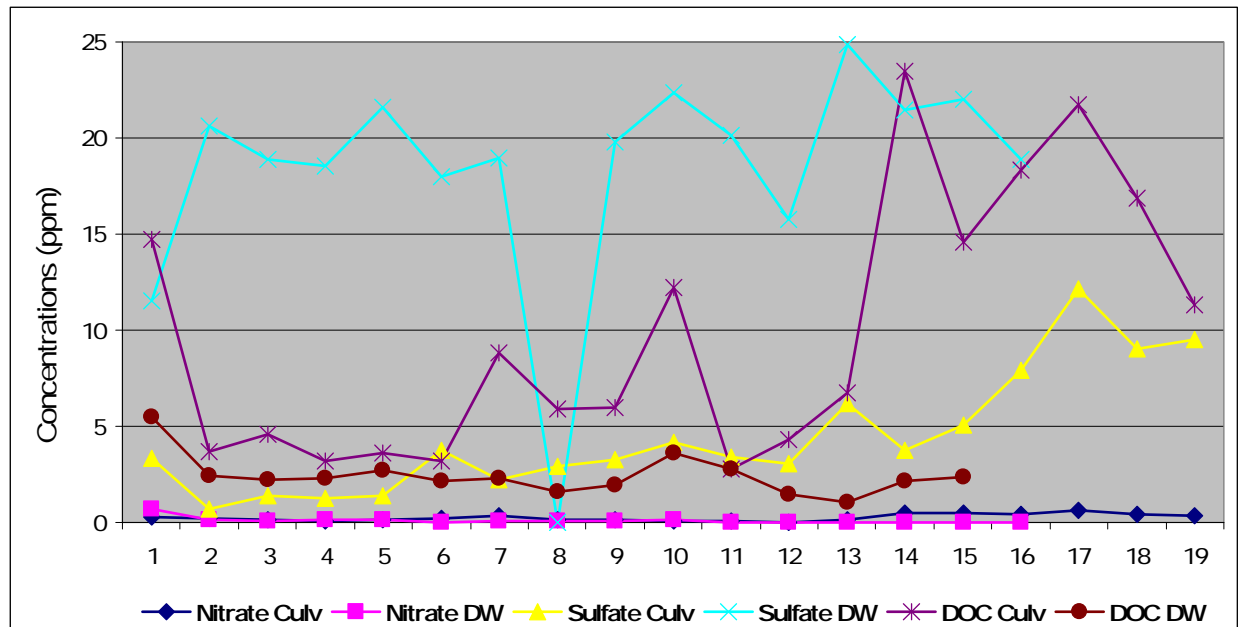


Figure 2. Inflow (Culv) and within-BMP (DW) quality of nitrate, sulfate and DOC to the Orange County suburban rain garden during a long storm on Sep. 06 and 07, 2008. Culv stands for culvert which is the inflow sampling structure and DW for deep well within the stormwater BMPs or rain garden.

The Orange County rain garden included autosamplers at a well penetrating to the bottom of the rain garden (Deep Well), and at a second well downgradient from the garden and above a nearby stream (Shallow well). In both wells, bromide, nitrate and DOC concentrations were similar for the pre- and post- rainfall event conditions with no significant differences (Fig. 3 and Fig. 4). The river nitrate concentration for the post- rainfall event condition (Fig. 4) was significantly higher (7.6 mg/l), approaching the nitrate standard of 10 mg/l for drinking water (EPA, 2003), and may pose a serious threat to water quality. Since the lower parts of the Hudson River basin including the Wallkill river watershed in Orange County where river samples were taken have new urban and suburban developments; these developments might be contributing to increase the nitrate stormwater-related loadings.

Since rain garden outflow nitrate concentrations were down below the nitrate standard of 10 mg/l, one can say that the management and treatment of stormwater runoff in urbanized and developing areas are threaten well by the stormwater BMPs (rain gardens) declining nitrate pollution levels.

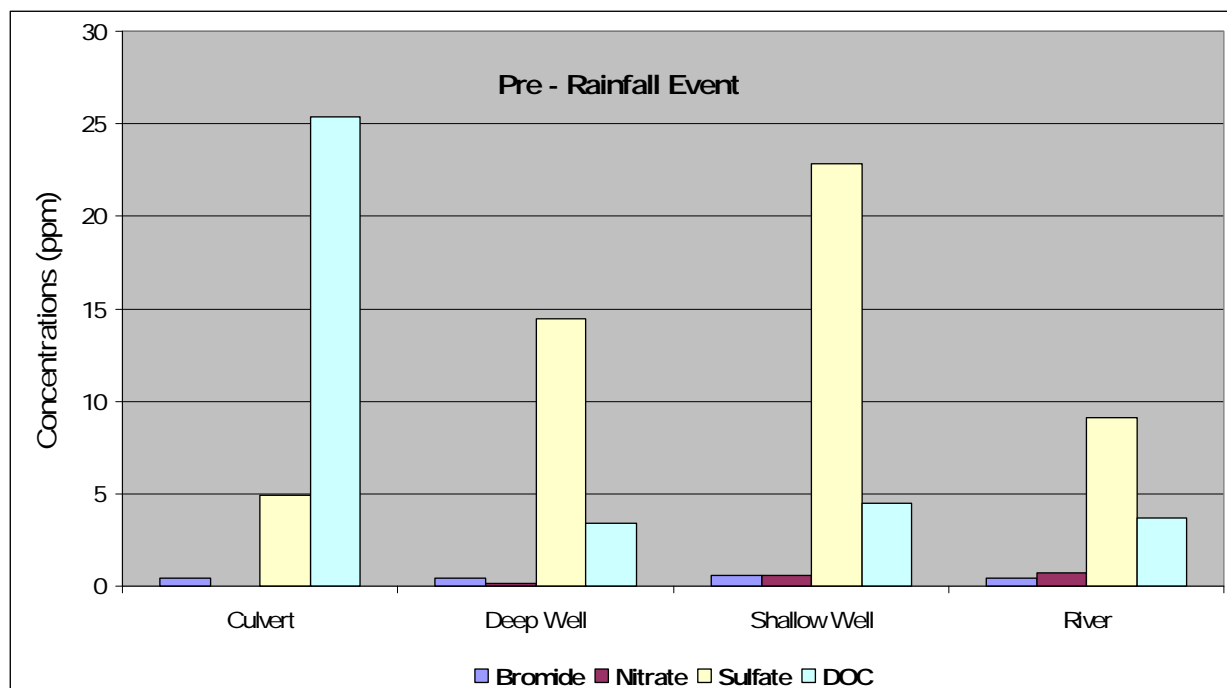


Fig 3. Pre-rainfall event quality conditions to the Orange County suburban rain garden during a long storm on Sep. 06 and 07, 2008.

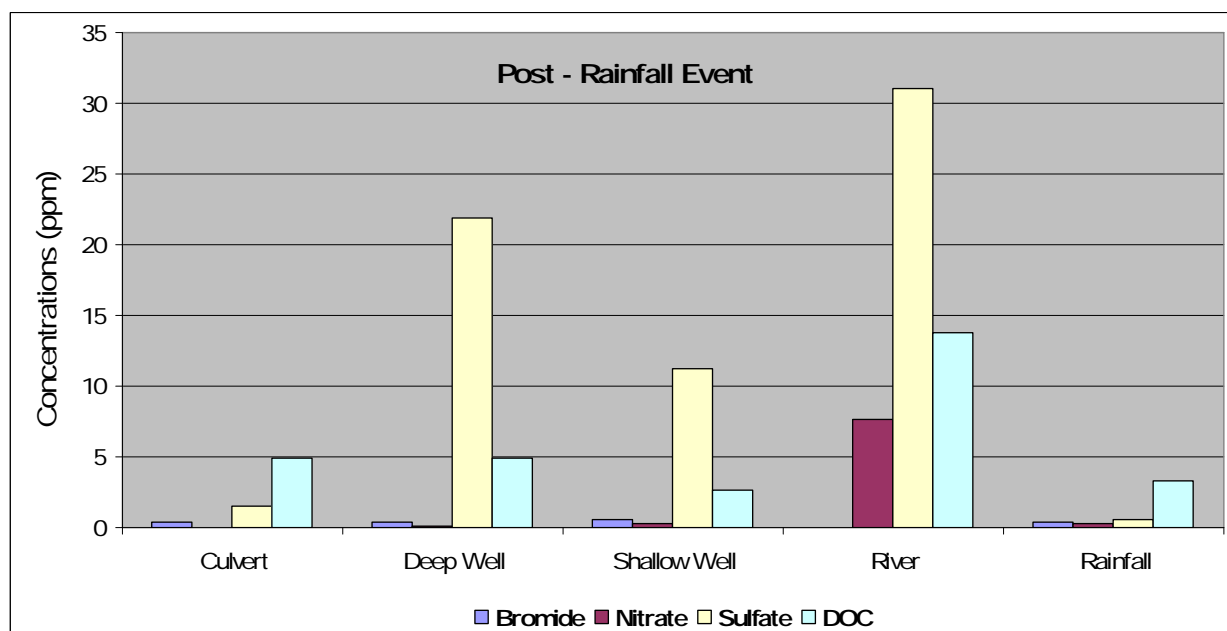


Fig 4. Post-rainfall event quality conditions to the Orange County suburban rain garden during a long storm on Sep. 06 and 07, 2008.

Although no statistical analyses have been performed for the results obtained from the Skaneateles rain garden samples, preliminary results show higher Fe and P average

concentrations in the rain garden subsurface flow (Table 1). These concentrations are significantly greater than the roof runoff source. The same is observed for rain garden subsurface flow nitrate concentrations in which the average nitrate concentrations peaked as well. This might indicate that the nitrate, Fe, and P source is the mulch layer itself, since lower concentrations were observed in the source area (roof runoff and rainfall). These findings contrast with Hsieh and Davis (2007) who mentioned that the mulch layer is important in heavy metal reduction (such as Fe), however it may add P to the system as was observed.

Nitrate average concentrations in rainfall (0.77 mg/l) and roof runoff (1.8 mg/l for rain garden #2 in Table 1) were higher than those reported elsewhere. Steuer, *et al.* (1997) reported a geometric mean nitrate concentration of 0.46 mg/l in residential roof runoff in Michigan and a geometric mean for nitrate of 0.68 mg/l was reported by Halverson (1984) in runoff from a residential roof in Pennsylvania. However, the nitrate average concentration in roof runoff for rain garden #1 was 0.24 mg/l which is 7.5 times smaller than the roof runoff for rain garden #2 although both building roofs are located in the same area and only 200 m separated apart. Further research into the roof material may indicate the difference in nitrate roof runoff concentrations.

A decreasing trend in DOC concentration was observed for rain garden #1 from rainfall (15.5 mg/l) to roof runoff (13.3 mg/l) to subsurface flow (7.3 mg/l) in the rain garden (Table 1). Although for rain garden #2 the same decreasing trend was observed from rainfall (15.5 mg/l) to roof runoff (8.7 mg/l), the DOC concentration peaked up to 36.2 mg/l in the rain garden subsurface flow (Table 1). Here again the mulch layer plays an important role in defining the DOC concentration and may add DOC to the system as well as was observed for P. These results suggest that conservative pollutants like heavy metals and persistent organics must be removed physically from the rain garden by harvesting the plants, removing the substrate (mulch layer) and plants and rebuilding with fresh material. Otherwise they can become saturated with the pollutants they concentrate and cease to be able to treat the stormwater flow.

Table 1. Observed average concentrations in sampling points for Rain Garden (R.G.) #1 and #2 located in the village of Skaneateles over the course of different rainfall events.

SOURCE	Fe	Mn	P	Pb	Zn	Cu	Cd	Bromide	Nitrate	Sulfate	Chloride	DOC
	----- mg/l -----						-----					
Rainfall	0.008	0.022	0.061	0.005	0.077	0.047	0.013	0.35	0.77	5.96	1200	15.5
Roof Runoff R.G. #1	0.015	0.010	0.017	0.016	0.022	0.030	0.003	0.36	0.24	3.12	921	13.3
Pavement Runoff R.G. #1	0.054	0.011	0.147	0.012	0.013	0.008	0.003	0.03	0.06	2.14	1230	13.2
Rain Garden #1	0.231	0.010	0.430	0.009	0.014	0.017	0.004	n.a.	2.19	2.24	946	7.3
Roof Runoff R.G. #2	0.060	0.009	0.420	0.147	0.028	0.011	0.007	0.32	1.80	2.01	1137	8.7
Pavement Runoff R.G. #2	0.137	0.015	0.045	0.009	0.036	0.007	0.004	0.07	0.16	1.65	1095	6.7
Rain Garden #2	0.284	0.013	1.865	0.021	0.048	0.013	0.006	0.26	3.60	4.28	1585	36.2
River	0.027	0.002	0.055	0.008	0.903	0.005	0.003	0.10	0.44	5.19	923	2.3

STUDENT SUPPORT

One research graduate student has focused on monitoring system design and installation, sampling, laboratory analyses, and data interpretation. This project has supported a graduate student partially for two semesters.

NOTABLE ACHIEVEMENTS AND AWARDS (INCLUDING PUBLICATIONS, THESIS, AND PRESENTATIONS)

Finals results will be incorporated in to a peer review journal during the remainder of 2009. Results will also be presented in a scientific meeting.

SYNERGISTIC ACTIVITIES (E.G. OTHER OPPORTUNITIES AND COLLABORATIONS THAT WERE ENABLED BY YOUR GRANT)

During the spring 2009 semester, the experience gained during the development of the project and preliminary results were used for supporting a class in the Department of Biological and Environmental Engineering including a class presentation for the project itself. The class was BEE 4740 Water and Landscape Engineering Applications that was combined with a Landscape Architecture class, and included site characterization, rain garden system design, soil sampling, and data interpretation. Students in the class were upper level undergraduate and beginning graduate level who were depth interested in the project's preliminary results since they have to design a rain garden for the class.

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Evaluation of sediment sources in the Hudson River Watershed

Basic Information

Title:	Evaluation of sediment sources in the Hudson River Watershed
Project Number:	2008NY105B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	22
Research Category:	Water Quality
Focus Category:	Sediments, Water Quality, None
Descriptors:	None
Principal Investigators:	Todd Walter

Publication

1. Shaw, S.B. and M.T. Walter. 2009. Estimating storm runoff risk using bivariate frequency analyses of rainfall and antecedent watershed wetness. Water Resources Research 45: W03404 [doi:10.1029/2008WR006900].
2. Shaw, S.B., R. Mahklouf*, M.T. Walter, J.-Y. Parlange, I. Lisle. 2008. Experimental testing of a stochastic sediment transport model. Journal of Hydrology 348(3-4): 425-430.
3. Tromp-van Meerveld, H.J., J.-Y. Parlange, D.A. Barry, M.F. Tromp, G.C. Sander, M.T. Walter, M.B. Parlange. 2008. Influence of sediment settling velocity on mechanistic soil erosion modeling. Water Resources Research 44: W06401 [doi:10.1029/2007WR006361].

Some Simple Analyses of Historic Stream Turbidity Data in the Esopus Creek Watershed, New York

Executive Summary

While lacustrine deposits in the Esopus Creek watershed are known to be a source of turbidity in the Ashokan Reservoir, it still remains unclear whether mobilized lacustrine sediments originate only from stream banks or also from upland, terrestrial sources. In this report, we examine three unique periods in the sampling record to try to gain insight into whether turbidity originates in-stream or upland. First, we evaluate a period of synoptic sampling on six Esopus Creek tributaries to highlight possible critical landscape features driving differences in sediment load between tributaries. Second, we consider differences in concentration-discharge curves for Esopus Creek when similar hydrograph pulses are generated from either storm events or diversions from the Schoharie Reservoir. Third, we use routine, monthly grab sample data to compare Esopus Creek tributary turbidity levels several months after large flood events in 1987, 1996, and 2005.

1. Introduction

Following large rainfall events, Esopus Creek can transport sizable amounts of suspended solids. As the primary tributary feeding the Ashokan Reservoir in the New York City (NYC) water supply system, these suspended solids can lead to in-reservoir turbidity levels that exceed regulatory standards for drinking water. From 1985 to 2005, alum was only applied four times to remove suspended sediment in the Catskill reservoir system, but in the last several years multiple storm events have required the addition of alum (NYCDEP 2006, pp 11-15). Consequently, in recent years, there has been an intensified effort to identify underlying mechanisms of sediment mobilization and transport in the stream system and means for minimizing inputs.

Ever since the Catskill system was first planned and surveyed in the early 20th century by the NYC Board of Water Supply, there has been an awareness that lacustrine deposits in area could potentially elevate turbidity levels (NYCDEP 2006, pp 11-15). For instance, the Ashokan reservoir was specifically built with two basins separated by a weir to maximize settling of suspended sediment and prevent short-circuiting of sediment laden water directly to the Catskill Aqueduct intake. The lacustrine deposits are a natural consequence of the Esopus Creek watershed's location in an ancient inland sea. While these deposits are the root source of high stream turbidity levels, there still seems to be no definitive conclusion on the division between upland, terrestrial contributions and in-channel contributions of the lacustrine material. Previous studies have established that Ashokan Reservoir sediment loads primarily originate from the Esopus Creek watershed (NYC Dep 2006), have studied sediment dynamics in reservoirs (O'Donnell and Effler 2006), and have geomorphologically evaluated Esopus Creek stream channels (Upper Esopus Creek Management Plan). However, there has been only a limited comparison of upland versus in-stream sources. A sediment budget in The Upper Esopus Creek Management Plan concludes that "a significant proportion of the assumed annual load is from unknown sources (2007, p 128)." The intent of this study is to assess sediment data collected by the NYC Department of Environmental Protection (DEP) between 1987 and 2008 to see whether there are any clues providing insight into the predominant mobilization and transport mechanisms of the lacustrine material.

This study will focus on three aspects of the data set:

1. The study will compare storm event samples of suspended solids collected on six Esopus Creek tributaries. This data will be compared to soil surveys, surficial geologic mapping, and recent stream surveys to see if presumed indicators of lacustrine deposits are corroborated by in-stream sampling.
2. Using turbidity measurements from near the mouth of Esopus Creek (sampling station E16i in Figure 1), the study will compare concentration-discharge curves from time periods where high Esopus stream flows are primarily due to diversion from Schoharie reservoir and when high stream flows are due to rainfall events. The Schoharie diversion acts as a kind of experimental control where stream discharge can be independent of rainfall and thus independent of upslope, terrestrial inputs.
3. The study will assess residual levels of turbidity in several Esopus Creek tributaries following major flooding events in 1987, 1996, and 2005. The flooding in 2005 ultimately led to nearly a year of alum application in the Catskill system. The study will clarify whether conditions had changed in the watershed from the 1980's and 1990's to 2005 that may have led to greater sediment export in 2005 and 2006.

2. Comparison of Turbidity Data from Select Tributaries

NYC DEP samples stream water quality parameters on an approximately monthly time interval at select locations. There is a limited summary of Esopus Creek tributary sampling in the Upper Esopus Creek Management Plan Appendix C that reports median annual concentrations. In general, monthly, non-storm event stream samples are of limited value to identify important differences in the sediment contribution from tributaries since most sediment is transported during storm events (however, later in the report we will assess this record of routine sampling following large flood events that increase turbidity for several months after the flooding ends).

However, in 1995 and 1996, NYC DEP measured suspended solid concentrations during storm events in six tributaries to Esopus Creek: Bushnelville Creek (BNV), Broadstreet Hollow (BRD), Woodland Valley (WDL), Stony Clove Stream (SCL), Little Beaver Kill (LBK), and Beaver Kill (BK). All streams were sampled during the same storm events and each stream was sampled multiple times during the event. Given that it is not possible to control the initial channel conditions and rainfall characteristics during an event in natural systems, one is usually left to try to compare among stream systems subject to greatly differing history and external influences. This synoptic sampling of tributaries in 1995 and 1996 provides a rare and relatively robust data set on which to make a cross-comparison of streams.

Each tributary has a potentially unique set of landscape, soil, geological, and land use characteristics. Comparing storm event suspended solid concentrations among tributaries provides an opportunity to identify characteristics that effect sediment export rates in the streams. All basins are primarily forested with some near-stream residential areas. Soil data was determined from the SSURGO database (<http://SoilDataMart.nrcs.usda.gov>) for Greene and Ulster counties, New York. Surficial geologic information was available from the New York State Museum (Albany, NY). Additionally, as part of the Upper Esopus Creek Management Plan (ref), there has been a field geomorphologic assessment of fine clay deposits in Esopus Creek. While the survey does not appear to have extensively sampled all the tributaries, it did identify

extensive fine sediment deposits on the lower section of Woodland Creek near its junction with the main channel of the Esopus.

The synoptic tributary sampling generally insures that the channel history (in terms of available sediment) and watershed soil moisture state are similar. And, while multiple samples during each event gives a sense if there is an outlier, the autocorrelation of event samples means that measurements cannot be treated as statistically independent samples. Also, with only stage data and no actual discharge data, we cannot calculate an overall load for each event or concentration-discharge relationships. Thus, for each event on each tributary, we simply select the maximum suspended solid (SS) concentrations. Table 1 summarizes these maximum SS concentrations as well as the median value for each tributary. Stony Clove (SCL) consistently had the highest SS concentrations across all storm events. Broadstreet Hollow (BRD) had the highest recorded SS concentration and frequently had some of the highest SS concentrations across events. Little Beaver Kill consistently had the lowest TSS concentrations and had the lowest median. Other tributaries were more variable, with generally low medians but several very high event concentrations.

The turbidity data is generally in agreement with a previously prepared narrative on typical stream turbidity levels in a DEP memo following April 2-3, 2005 Flood in the Esopus Creek watershed. The narrative notes that Beaver Kill, Little Beaver Kill, and Bushnellsville Creek consistently run clear very soon after a storm event. Woodland Valley has moderate turbidity, becoming clear a few days after rainfall events. Furthermore, the narrative notes that Stony Clove has historically been a consistent source of suspended solids, and Broadstreet Hollow has several acknowledged sources of sediment.

A visual comparison of the measured SS concentrations to soil information is shown in Figure 1. [Alluvium category drawn from soils classified as either alluvium or fluvaquents in the SSURGO data. The Lacustrine category includes Madalin and Hudson soils. A summary of soil parent material in the Greene County soil survey (Table 19) identified lacustrine soils.] Alluvium can consist of material ranging from large cobbles to sand and silt but generally indicates proclivity for movement. Overall, lacustrine deposits identified by the soil survey did not correlate to SS concentration data. For instance, as shown in Figure 1, Beaver Kill (BK) had the most extensive lacustrine deposits but only had moderate SS concentrations. Other researchers have noted the fact that streams are likely to have incised soil layers not evident from a soil survey that only assessed soils near the ground surface (Nagel et al. 2007). Additionally, the soil survey does not recognize small-scale heterogeneities since it makes use of similarity of landscape features to assign soil types to areas not directly sampled (USDA p 5).

The surficial geologic information available for the region was too coarse and did not indicate any difference s between channel tributaries. The stream channel survey indicated fine sediment deposits along the lower reaches of the Woodland Valley (WDL) tributary. However, as summarized in Table 1, from the synoptic sampling the relatively low turbidity levels in WDL did not indicate that these sediment deposits had any sizable role in dictating tributary turbidity levels.

In general, descriptors of stream reaches available from geospatial data or previous watershed mapping or survey does not appear sufficient to identify actual differences in stream behavior. It remains a major challenge in to identify easily measured metrics that actually relate to observable differences in landscape processes.

3. Assessment of Esopus Creek Turbidity During Periods of high Schoharie Diversion

The Shandaken Tunnel (USGS gage #01362230) diverts water from the Schoharie Reservoir to Esopus Creek near Allaben, NY. The Shandaken tunnel diversion is operated so that flows in Esopus Creek will not exceed 465 cubic feet per second (cfs) between June 1 and October 31 (thus, only the difference between 465 cfs and natural Esopus flow can be diverted). Larger diversions are permitted to minimize spill from the Schoharie reservoir when Ashokan has available storage capacity (also during 2006, repairs on Gilboa Dam led to larger diversions).

For our investigation, we are interested in the occasional periods when the Schoharie diversion is rapidly increased, presumably to minimize spill from Schoharie reservoir. In the Esopus Creek hydrograph, these rapid increases in discharge tend to resemble small storm events. The rapid rise in water and associated hydrodynamic forces acting on stream banks should be similar for these Schoharie diversions and storm-event driven discharges. Thus, if bank erosion along the main stem of Esopus Creek is a source of sediment entering Ashokan reservoir, concentration-discharge curves for actual storm events and Schoharie diversions should be relatively similar.

Stream turbidity data is provided by the Robohut sampler maintained by the NYC DEP located at station E16i on Esopus Creek, just upstream of Ashokan Reservoir (see Figure 1). A nearby USGS stream gage (USGS #01362500 at Coldbrook, NY) provides stream discharge data. Both stream and turbidity samples are available at a 15-minute interval.

Based on the Shandaken Tunnel operational requirements, there have only been several instances in the last few years when a brief, high discharge (up to 700 cfs) pulse of water resembling a storm event was released from the Schoharie Reservoir through the Shandaken Tunnel. We identified such events on 7/14/2004, 7/16/2005, and 9/2/2005. Most releases are at lower discharge and sustained over a multi-day or week period. For comparison, we only select rainfall-driven discharge events of similar magnitude as the diversions (about 1000 cfs maximum discharge). Our rain events take place on 7/14/2004 and 7/8/2005.

Schoharie Reservoir diversions and rainfall driven discharges are compared by looking at concentration-discharge curves. Stream suspended solid concentration or turbidity (C) is frequently found to be highly dependent on instantaneous discharge (q), and this relationship can be visually assessed by plotting C versus q (referred to as a C - q curve). Figure 2a and 2b show the C - q curves for 2004 and 2005, respectively. For the events initiated by actual rainfall, we show both the rising and falling leg of the C - q curve separately to better explain variability in the C - q relationship since they tend to display a hysteresis effect.

As shown in Figure 2, rainfall driven discharges on Esopus Creek have distinctly different C - q curves than discharges driven by Schoharie diversions. Rainfall-driven discharges have C - q curves with a strong, positively increasing relationship between C and q (7/14/2005 and 7/8/2006 events). In contrast, diversion-driven discharges generally have a weak, positive relationship

between C and q with C only slightly increasing as q increases at least four times over. The 9/2/2006 discharge-driven event has a brief period when C greatly increases with q , but then C drops even though q remains high. This may be an illustration of the flushing of readily mobilized material from the channel although the diversion-driven pulse does not have sufficient energy to erode additional material.

By separating channel flow from rainfall, we can directly assess the role of both upland, rainfall driven processes and in-channel processes on sediment transport. We clearly see that turbidity only slightly increases when increases in discharge are due to Schoharie diversions alone. At least along the main channel of Esopus Creek between Allaben and Ashokan Reservoir, bank and bed erosion within Esopus Creek itself appears to be a minor source of sediment during relatively small flow storm events (event discharges of equal or greater intensity occur at least 5 times per year).

4. Stream Turbidity Following Major Storm Events

There has been a major flooding event in the Esopus Creek watershed since the mid 1980's. However, as noted earlier, multiple alum applications were required following the 2005 flooding event, more than had been required in the previous two decades. Thus, this component of the study seeks to assess whether there was any fundamental change in sediment availability in the Esopus Creek watershed following the April 2005 flooding.

The major flooding events of the last two decades on Esopus Creek occurred on 4/3/2005, 1/19/1996, and 4/4/1987; instantaneous peak discharge at the USGS stream gage on Esopus Creek at Coldbrook were 55,000 cfs, 53,600 cfs, and 51,700 cfs, respectively, for each date. These instantaneous flood peaks are approximately equivalent to 15 year return period flood events. As a matter of comparison, the largest flood event on record (since 1932) occurred on 3/21/1980 and had a peak discharge of 65,300 cfs.

We compiled the routine stream monitoring data for the main stem of the Esopus and four tributaries (Beaver Kill, Broadstreet Hollow, Woodland Valley, and Stony Clove) for approximately 200 days following each major flood event. Of the tributaries, Stony Clove (SCL) and Broadstreet Hollow (BRD) traditionally have been found to have higher turbidity levels than Beaver Kill (BK) and Woodland Valley (WDL), as seen in the synoptic sampling in Section 2. Routine monitoring was decreased in frequency from approximately semi-monthly in the 1980's and 1990's to monthly in 2005.

In Figure 3, we show stream turbidity for the main channel of the Esopus (E16i) and a high (SCL) and low turbidity (BK) tributary. In terms of main channel turbidity (Figure 3c), for the 200 days following the 4/3/2005 flood, turbidity levels were in the same range as those observed following the 1996 and 1987 floods. In all three years, turbidity remained higher than its long-term average baseline value of around 4 NTU. This suggests that channel and soil stability in the Esopus Creek watershed following the 2005 flooding event was not necessarily different than that from other major floods in the decades before.

Despite main channel turbidity levels being similar, tributary turbidity levels differed more noticeably between major flood years. For instance, in both SCL (Figure 3b) and BK (Figure

3a), 1996 stream turbidity over the 200 days post-storm was higher than either 1987 or 2005 stream turbidity. If BK and SCL turbidity were high in 1996 but overall Esopus main channel turbidity was similar to other years, there must be other low-turbidity reaches to counteract the high source loads. Conversely, in 1987 and 2005, there must be other high turbidity reaches to counteract the relatively low contribution from SCL and BK. In general, this suggests that dominant sediment sources do not remain constant over time but may shift position within the watershed.

5. Conclusions.

Our analysis was simple and based on limited data. In part, this was because routine, non-storm data collection that comprises the bulk of the data set available for the Esopus Creek watershed—while important for demonstrating adherence to water quality standards—has limited value in clarifying physical processes.

Overall, we offer several possible considerations for additional sampling and analysis that could help elucidate sediment mobilization and transport processes:

1. Region-wide geospatial data does not provide sufficient resolution to identify the small-scale features important to predicting sediment loads in the stream (a conclusion in part stated by Phase I of the Upper Esopus Creek Management Plan Study). Field-scale observation and mapping of channel and subcatchment features are most likely needed to clearly identify characteristics that enhance stream sediment export.
2. Geomorphologic assessments of stream tributaries—instead of just the main channel—may offer opportunities to validate apparent differences in observations of channel features against actual differences in measurements of stream sediment export.
3. The comparison of $C-q$ curves for rainfall driven and diversion driven Esopus discharges suggest that channel erosion is a minor component of the sediment load in the main channel of Esopus Creek between Allaben and Ashokan Reservoir. If there are any Esopus Creek tributaries with upstream impoundments, it may be insightful to artificially release a large pulse of water to see if stream tributaries behave differently than the main channel when comparing in-stream releases to rainfall-driven events.
4. Long-term Esopus Creek turbidity levels following the April 2005 flooding event were generally similar to those observed for large storms in 1996 and 1987. However, somewhat surprisingly, turbidity levels in Esopus Creek tributaries following the April 2005 flood were generally lower than seen after the 1996 flood and equivalent to levels after the 1987 flood. This suggests that between major flooding events, dominant sources of sediment to the main stem of Esopus Creek may change. But, there does not appear to be a more severe deterioration of the stability of soils and channels in the watershed compared to two decades earlier. Analysis of data from even earlier flood events (i.e. 1980 flood) may provide further insight into long-term changes in the Esopus Creek watershed.

Student Support: Stephen Shaw (PhD)

Synergistic Activities: This project overlapped with a number of erosion and sediment transport related projects in our lab. We are using this project as part of the proof-of-concept underlying

an NSF proposal that will be submitted to the Geomorphology program in July. Notable publications are listed below.

Publications: (* indicates undergraduate co-authors)

Shaw, S.B. and M.T. Walter. 2009. Estimating storm runoff risk using bivariate frequency analyses of rainfall and antecedent watershed wetness. *Water Resources Research* 45: W03404 [doi:10.1029/2008WR006900].

Shaw, S.B., R. Mahklouf*, M.T. Walter, J.-Y. Parlange, I. Lisle. 2008. Experimental testing of a stochastic sediment transport model. *Journal of Hydrology* 348(3-4): 425-430.

Shaw, S.B., J.R. Stedinger, M.T. Walter. 2009. Evaluating urban pollutant build-up/wash-off models using a Madison, Wisconsin catchment. *Journal of Hydrology* (accepted with minor revisions)

Shaw, S.B., M.T. Walter, J.-Y. Parlange. 2009. Accounting for surface roughness in a physically-based urban wash-off model. *Journal of Hydrology* 367(1-2): 79-85.

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Tromp-van Meerveld, H.J., J.-Y. Parlange, D.A. Barry, M.F. Tromp, G.C. Sander, M.T. Walter, M.B. Parlange. 2008. Influence of sediment settling velocity on mechanistic soil erosion modeling. *Water Resources Research* 44: W06401 [doi:10.1029/2007WR006361].

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O'Donnell, D.M. and S.W. Effler. 2006. Resolution of Impacts of Runoff Events on a Water Supply Reservoir with a Robotic Monitoring Network. *Journal of the American Water Resources Association*, April 2006: 323-335.

UECMP V III. Draft 1/25/2007.

UECMP V.III Appendix C CD2.2-NYCDEP SMP memo on Esopus Creek Turbidity from April 2005 flood

Soil Conservation Service. 1993. Soil Survey of Greene County, NY. USDA, February 1993.

Tables.**Table 1.** Peak suspended solid concentrations sampled on six Esopus Creek Tributaries during 7 different storm events.

Dates	Suspended Solids (mg L ⁻¹)					
	LBK	BK	SCL	WDL	BRD	BNV
10/21/1995	500	560	1468	542	988	1068
4/16/1996	107	588	944	312	820	768
4/29/1996	70	223	246	89	171	56
4/30/1996	65	454	502	192	394	127
5/1/1996	16	143	219	47	156	40
11/9/1996	56	396	1100	200	2270	127
12/2/1996	281	1400	1100	724	1030	680
Median	70	454	944	200	820	127

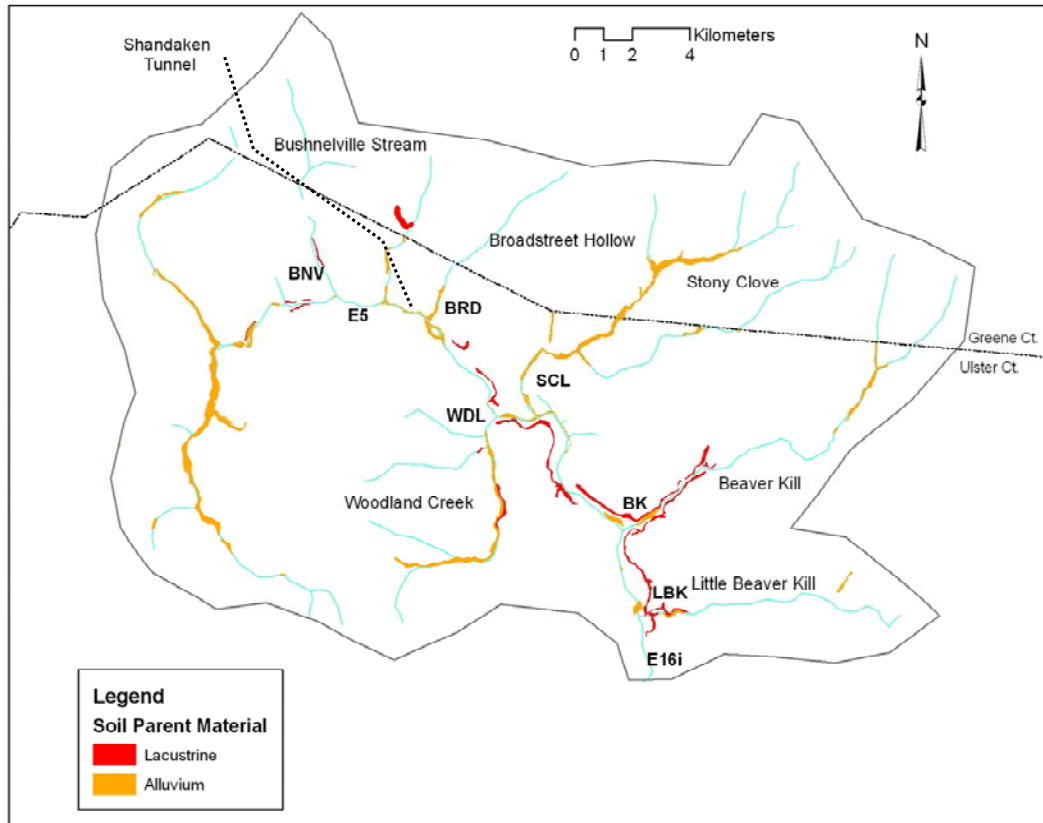
Figures

Figure 1. Map of water quality sampling locations and near-stream soil types in the Esopus Creek watershed.

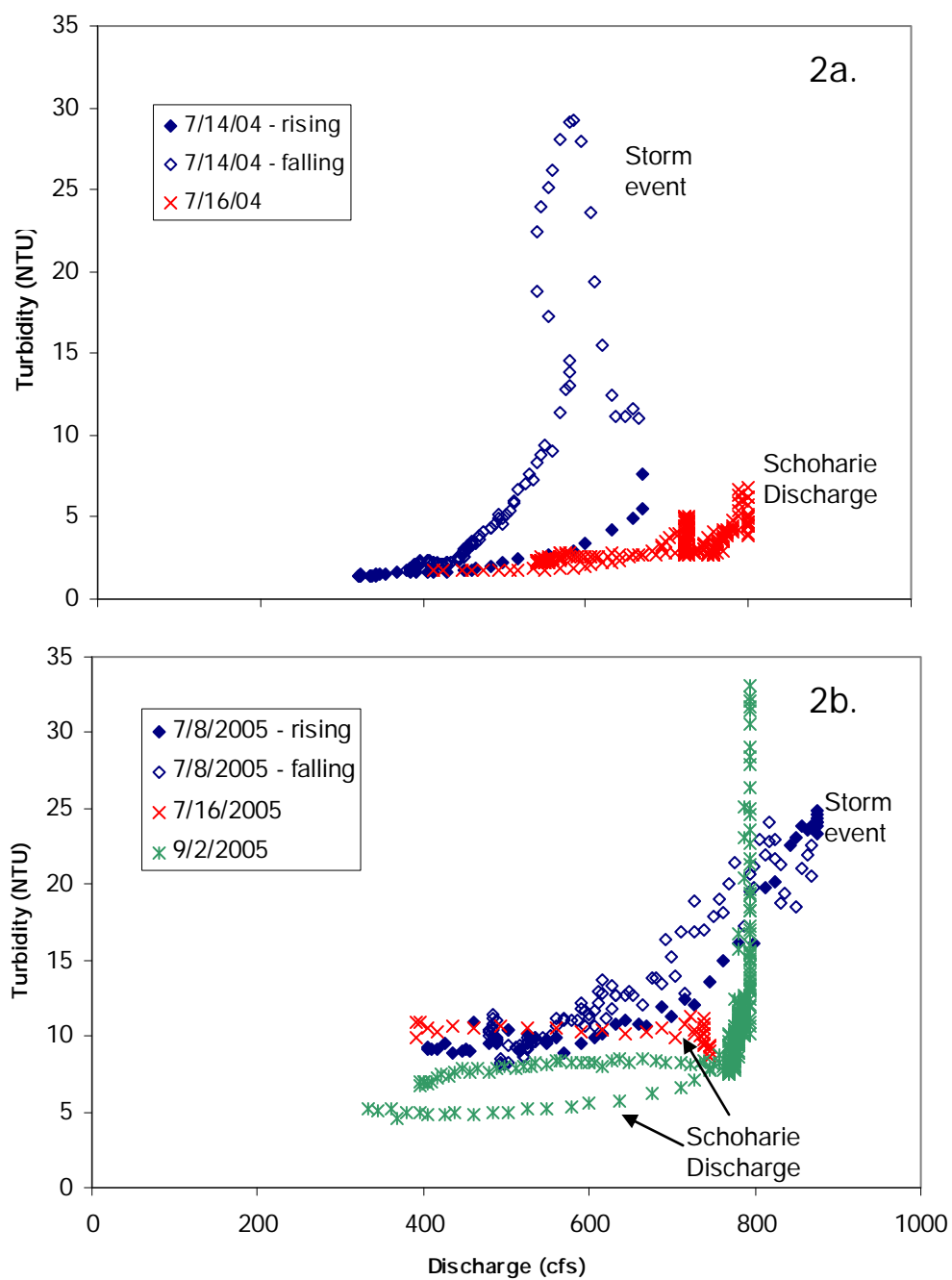


Figure 2. Concentration-discharge curves at sampling Station E16i on Esopus Creek for select storm and Schoharie Reservoir discharge events.

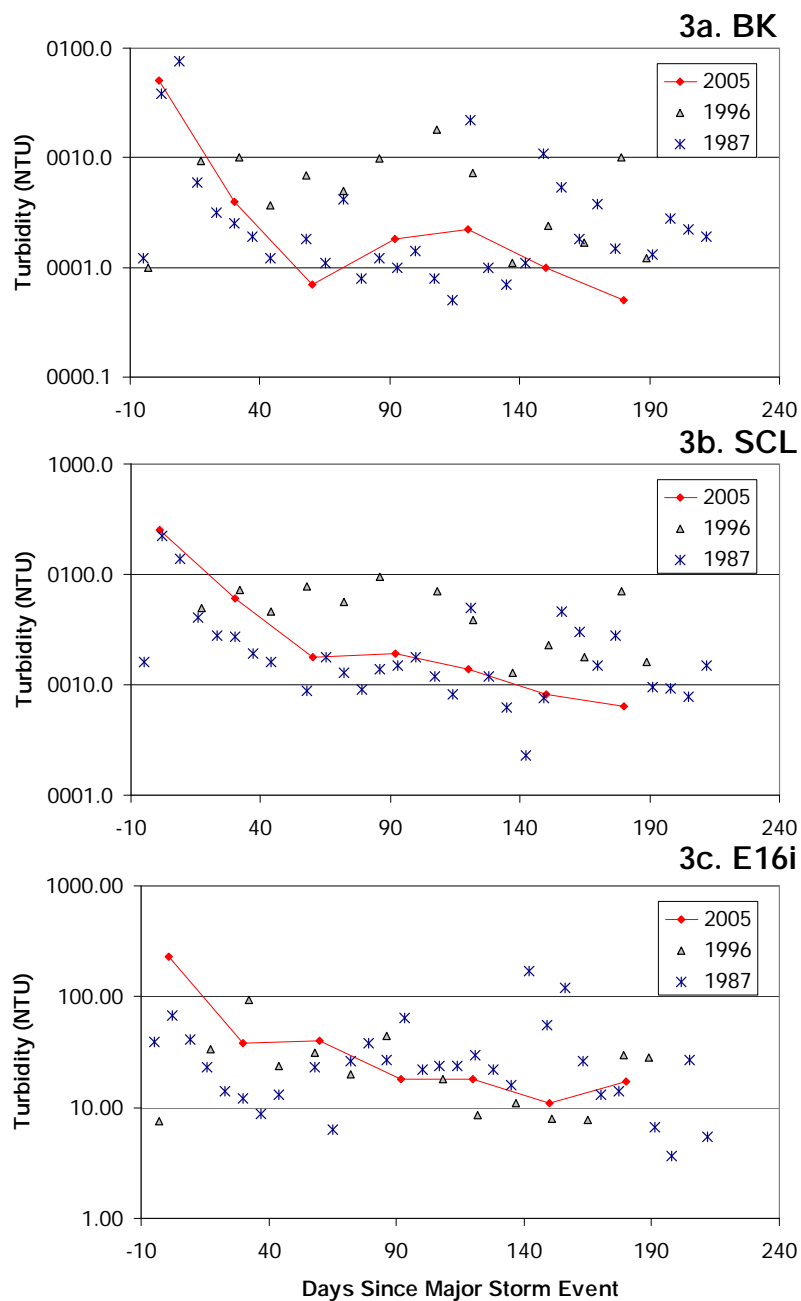


Figure 3. Turbidity on Beaver Kill (BK) tributary, Stone Clove tributary (SCL), and the main stem of Esopus Creek (E16i) following major flooding events in 1985, 1996, and 2005. The x-axis indicates days since the major flood initiating event has occurred.

Prediction of areas sensitive to fertilizer application in thinly soiled Karst

Basic Information

Title:	Prediction of areas sensitive to fertilizer application in thinly soiled Karst
Project Number:	2008NY106B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	26
Research Category:	Ground-water Flow and Transport
Focus Category:	Groundwater, Water Quality, None
Descriptors:	None
Principal Investigators:	Paul L. Richards

Publication

1. Voortman, B. and Simons, G. (2009) The role of local runoff generation in karst-related floodings between Le Roy and Caledonia, NY, Joint Master's Thesis, Utrecht University, Holland
2. Payne, C. (2009) Stratigraphic Analysis of the Onondaga Formation and Relationships with Groundwater Flow, Case Study in Leroy, New York, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport.
3. Daniluk, T. (2009) Source of Flood Water at the Quinlan Road Sinkhole Leroy, New York, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport.

Prediction of Areas Sensitive to Fertilizer Application in Thinly-Soiled Karst

by

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PROGRESS REPORT MAY 15, 2009

SUMMARY

A careful analysis of surface depressions, fracture trace features, gas logs and aerial photography in conjunction with field surveys was used to identify karst features that are sensitive to groundwater contamination.. Our hypothesis is that portions of the watershed that are underlain by fractures and fast-dissolution pathways can be recognized from their surface topographic expression and relationship to fracture traces. Our methodology consisted of identifying closed sinks in a 10 meter digital elevation model. From this analysis over 800 features were identified in the study area. Aerial photography was then analyzed for evidence of hydrologic activity and the sites were superimposed on hydrography to identify swallets and springs. Gas logs were evaluated to determine depth to bedrock. The results suggest many scales of closed depressions exist in the Onondaga FM.. These features resulted from a complex history of karst and glacial processes as well as anthropogenic activities such as quarrying and landscape alteration. Fracture traces, particularly those that are parallel to the the major fracture systems (N40-55E and E10-15S), contained systems of sinkholes. Close inspection using aerial photography and field surveys conducted in March 2009 show that many of these features are hydrologically active in the early spring. The DEM approach for identifying depressions provided a reasonable starting point for this analysis, however, it missed many features from aerial photography that are interpreted to be sinkholes. These features were mapped from aerial photography and checked in the field. Sinkholes appear to be depressions caused by enhanced weathering along heavily fractured zones and fracture traces. Some of these appear to be collapse features, with large fragments of limestone bedrock in steeply-walled depressions. It is interesting to note that two of these "collapse" features occur at the intersection of major north-east and western fracture traces. Recharging surface waters at the intersection is believed to have caused enhanced weathering, eventually causing the overlying bedrock to collapse. Others are elongate depressions, or depression complexes that occur along fracture traces. There are also flat fractured areas with no obvious surface expression that appear to be hydrologically active.

Our interpretation is that groundwater flows into the area through a series of north trending fracture traces. Some of this flow is believed to be shallow and flows on top of the Oatka Creek and Levanna shales, which acts as an aquitard. Deep groundwater flow also occurs in the Onondaga FM itself. We believe this type of flow system extends all the way across western New York State. Once the groundwater flow into the Onondaga FM, it will flow laterally through open fractures to stream valleys that make up piezometric lows. In Leroy, studies by Dunn et al (1992) show the dominant groundwater direction in the Onondaga FM to be eastward through open fractures. This flow direction is significantly different from the direction of surface flows and rivers. From our field observations

and previous research we suggest the following 5 hydrological mechanisms may be responsible for rapidly moving nutrients into the groundwater table; *contact flooding*, *groundwater mounding*, *perched water table transfer*, *rapid recharge into vertical fractures*, *swallet flooding*.

1. **Contact flooding**; near the interface of the Onondaga FM and the Oatka Creek shale, deep groundwater flowpaths and shallow water flows converge causing the water table to rise. In places this water table can reach the surface causing the floods that are observed along this interface. As the water table rises into the soil zone, nutrients can get washed from the soil and are spread laterally in the direction of the peizometric surface. This could be in any direction depending on the resulting shape of the peizometric surface. This phenomenon may also be enhanced by a release in confining conditions in places where the Levenna shale acts as an aquitard.
2. **Groundwater mounding**; fracturing in the Onondaga FM is not uniform and there exist zones where the conveyance capacity of fractures can be lower than the rate of allogenic recharge. Groundwater flow into these areas when combined with snow melt, precipitation, and perhaps water from impervious runoff, liquid fertilizer application and septic field inputs, can sometimes exceed down gradient flow rates. This will cause the water table to rise (mound). In places, the water table could rise up to the soil zone, potentially washing out accumulated nutrients. This seems most likely to happen in topographic lows and depressions. Sinkholes are also natural 'release valves' for groundwater if the storativity of the aquifer is completely used up. The sinkhole complexes at Quinlan rd and Buckley Rd are probably examples of this.
3. **Perched water table transfer**; Shallow perched water tables in the epikarst zone could potentially cause infiltrated, nutrient rich water to move laterally long distances. When these waters intersect solution widened vertical fractures they will flow down to the groundwater table.
4. **Rapid recharge into vertical fractures and conduits**; this is the traditional view of recharge where descending waters carry surface pollutant downward to the water table in solution-widened vertical conduits and fractures. This was believed to occur during a 2007 well contamination event in Batavia. It is important to note that the area where this occurred was not associated with a depression or other surface expression. It represented the base of a farmed slope where fractured bedrock was exposed and bounded by an end moraine deposit.
5. **Swallet flooding** is flooding at the end of tributaries that are terminated by sinkholes. If stream discharge exceeds the conveyance capacity of the sinkhole, flooding could occur, potentially washing surface pollutants from distant areas. This may also inundate the epikarst in distant areas which can trigger some of these other phenomenon. This occurs at several streams terminating in Caledonia and Leroy.

Each of these types of groundwater/surface water interaction will be expressed differently at the surface and will have unique propensities for delivering nutrients into the groundwater table. They will also be triggered by different sets of hydrometeorologic conditions and are sensitive to agricultural activities in different ways. Traditionally, the concern is water flowing down from the soil zone which carries with it pollutants derived from the surface. This process is assumed to be controlled by the transmissivity and vertical hydraulic gradient in the soil and bedrock and is modeled as such. But with *groundwater mounding* and *contact flooding*, the process is not controlled by soils, but rather its location and the position of the peizometric surface. For these situations we hypothesize that surface pollutants such as manure and liquid fertilizer will accumulate over long time periods in the hollows and voids that make up the base of the epikarst zone. During groundwater mounding events the water table will rise up, inundate these regions, and wash material laterally to open fractures. Models for mapping sensitive areas based on soil properties will not be able to identify these situations, but we believe they are mappable if one understands the location of the peizometric surface relative to the elevation of the base

of the epikarst zone.

MAJOR FINDINGS SO FAR:

1) Sinkholes are associated with major fracture traces that follow fractures directions evaluated by Engelder and students. Their mapping, which extends across the state could potentially be used outside the study area. Two of the larger collapse-type sinkholes appear to be located at the intersection of major fracture traces, implying that where fracture traces intersect should be considered important locations of concern.

2) Many of these features are hydrologically active. The April 2005 flyover captured a large number of these features in flood stage. This aerial photography set, which exists in some counties outside Genesee County, could potentially be used outside the study area for identifying sinkholes that are hydrologically activity and susceptible to groundwater contamination. Field surveys and discussions with locals living near them were very useful for identifying where surface water is being lost into the subsurface.

3) Anthropogenic depressions exist in the area. These are common along transport corridors and railroad lines. Many appear to be old gravel pits and quarries. At least one of these exhibit the same hydrologic behavior as the hydrologically active sinkholes. They probably should be considered sites of concern, because they represent areas with little overburden and are close to bedrock.

4) Transducer data and water level measurements collected by this study suggest water tables are extremely dynamic, with water tables rising in the early spring as fast as 50 feet per day. These tend to occur between February and April. Not all wells show water table fluctuations of this magnitude, but many have water tables rises that are 15 feet or more per day and all have large annual variations. The precise timing of water table fluctuations in wells and sinkholes separated by large distances, combined with the lack of apparent relationships between karst related-flooding and precipitation and snow melt variables imply that these water table rises are a large scale (regional) phenomenon and not due solely to local hydrogeological characteristics. The presence of rapid water table rises over a broad area has profound implications on vapor intrusion processes. At least one major TCE plume exists in the study area with know vapor intrusion issues. Future vapor intrusion sampling should account for this water table behavior.

5) Our hypothesis that the regional water table occasionally rises into the epikarst zone (*groundwater mounding*) has been confirmed in two portions of the field area. Several examples of *swallet flooding* are also present.

6) Water quality analyses of groundwater fracture flow confirm that subsurface flowpaths are capable of transporting significant amounts of phosphorous. Several of these samples show suspended solid concentrations that are similar to concentrations in surface waters.

7) There is some evidence that the Nedrow member of the Onondaga FM is not as important for fracture flow as the Moorehouse and Edgecliff members. The Seneca Member is not present in the study area. Quarry exposures indicate the basal unconformities and vertical joints in the Moorehouse and edgecliff members are important flow conduits.

PUBLICATIONS

To date, this research has supported two undergraduate theses, a graduate thesis and four conference presentations at major scientific meetings (see citations below). This research is continuing to support one other undergraduate thesis which should be finished in 2010. We anticipate all GIS products to be completed by June 2010. Two conference talks by the PI at this year's combined FL-LOWPA/USGS/ FLI meeting (in October, 2009) will formally present the results of this research. We are on track for finishing the depth to bedrock map and geophysical characterization of the major types of depression and fracture trace features.

Libby, J. L., Carney, H., Daniluk, T.L., Noll, M.R., Richards, P.L. and Craft, J.H. (2008) *Phosphorus Dynamics in a Karstic Groundwater-Surface Water System in Western New York*, 2008 Annual Meeting, GSA, Houston, TX, poster presentation. This poster was also presented at the 2008 Annual Conference of the Finger lakes Institute.

[Daniluk, Timothy L.](#), Libby, Jill L., Richards, Paul L., Craft, James H., and Noll, Mark R. (2008) *Seasonal Water Table Variations in the Onondaga FM, Western NY*, 2008 Annual Meeting, GSA, Houston, TX, oral presentation. This talk was also presented at the 2008 Annual Conference of the Finger lakes Institute.

Daniluk, T. (2009) *Source of Flood Water at the Quinlan Road Sinkhole Leroy, New York*, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport.

Payne, C. (2009) *Stratigraphic Analysis of the Onondaga Formation and Relationships with Groundwater Flow, Case Study in Leroy, New York*, Undergraduate Thesis, Dept. of Earth Sciences, The College at Brockport.

Voortman, B. and Simons, G. (2009) *The role of local runoff generation in karst-related floodings between Le Roy and Caledonia, NY*, Joint Master's Thesis, Utrecht University, Holland

GIS PRODUCTS

This research has produced the following GIS products so far:

Fracture trace map
Streams terminating in the Onondaga FM
Streams originating in the Onondaga FM
Suspicious sinkholes

Preliminary versions of these data sets in GIS format (shapefiles) have been turned over to Bill Kappel and James Reddy (USGS) to be used in their survey of karst features in Genesee County. Copies of these products have also been given to George Squires of the Genesee County Soil Water Conservation District.

Application of stream landscape theory for the restoration of Hudson Valley Watersheds

Basic Information

Title:	Application of stream landscape theory for the restoration of Hudson Valley Watersheds
Project Number:	2008NY107B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	22
Research Category:	Water Quality
Focus Category:	Surface Water, Conservation, Water Quality
Descriptors:	None
Principal Investigators:	Mark Bain

Publication

Application of Stream Landscape Theory for the Restoration of Hudson Valley Watersheds

Project Report

By

Mark Bain

and

Michael Wine

For the

New York State Water Resources Institute

and the

Hudson River Estuary Program

New York Department of Environmental Conservation

15 May 2009

Problem Statement and Research Objectives

Barriers that impede or obstruct the passage of fish along streams can reduce the diversity, abundance, and size range of fish (Schlosser 1991, Gowan et al. 1994). While barriers to migratory fish have been recognized as a problem from the time colonists occupied the Hudson Valley, detrimental effects of dams on resident stream species have been recognized only recently (Gowan et al. 1994). Fragmented streams and watersheds on average support fewer fish, fewer species, and a reduced size range of individuals than networks of diversified stream habitats (Schlosser 1995, Harig et al. 2000, Harig and Fausch 2002, Letcher et al. 2007). Sometimes called stream landscape theory or the riverscape concept (Ward 1998, Fausch et al. 2002), the key idea is that fish movement plays a pivotal role in connecting different life stages to patches of optimal habitat through their life cycle. We believe that allowing free movement by reducing stream fragmentation can result in larger, more diverse, and better secured populations with a greater range of fish sizes.

Defragmenting substantial portions of northeast watersheds is feasible. Many small dams in New York are old, deteriorating, and currently serve no useful purpose. These dams and obstructions, if identified as barriers, may be candidates for removal and other states have established barrier removal programs. In this project, we tested the prediction of stream landscape theory in two highly fragmented watersheds in the Hudson River Valley. If the conservation argument can be tested and found valid, the case will be made for dam removal to defragment watersheds,

Our goal is to provide support for the Hudson River Estuary Program (HREP) to promote stream landscape theory as a justification of watershed restoration projects that can enhance stream fish and aquatic life in the Hudson River valley. We want to do this with existing data largely from New York Department of Environmental Conservation (NYDEC), specifically the HREP barrier surveys. Our specific objectives are to:

1. Test predictions of stream landscape theory – Assemble NYDEC fish collection data by stream fragment and test the predictions that more diverse fish communities (species richness and size composition) with more individuals occur in large stream fragments.

2. Demonstrate the value of NYDEC and HREP data sets – Determine if watershed scale and historical data can be used to test predictions of stream landscape theory.
3. Present the conservation case – Develop and make presentations of the benefits and opportunities for enhancing stream habitat by eliminating barriers and reducing fragmentation.

Methodology

Our study was conducted using two watersheds and nearby Hudson River tributaries that were surveyed by the HREP for barriers. Moodna Creek on the west side of the Hudson River in Orange County, and Fishkill Creek and nearby streams on the east side of the Hudson River in Dutchess and Putnam Counties. Geographic Information System (GIS) files were provided by the HREP and fish collections were extracted from the NYDEC Bureau of Fisheries fishery survey databases.

Stream fragments

For both study areas, the HREP developed a distributional analyses of dams and barriers. Potential dams were located by visually scanning stream channels using aerial photographs (7.5 in per pixel true color orthoimages, 12 in per pixel infrared orthoimagery, New York statewide digital orthoimagery). Most identified stream barriers were then field verified from June through September 2005 by HREP staff, and for some streams by trained volunteers with photography and standardized field notes. However, the HREP investigators do not believe the generated barrier distribution is free of errors. GIS coverages were developed from the ground-truthed orthoimages using Arc GIS 9.0. All digitizing was done at a 1:2000 scale by the same HREP analysts who was also completed the field surveys. A review of the development of the data were reported by (Sayles 2005, Whyte 2006) and we obtained the resulting GIS files.

The editor tool in ArcGIS 9.3 was used to split, merge and measure the hydrography of Moodna and Fishkill creeks and the length of stream sections between barriers. We counted all stream channels in tributaries for each fragment length. Impounded surface water was subtracted from stream fragment lengths. Stream fragments with direct connections to the Hudson River and presence of marine and estuarine fish were

deleted. Where uncertainty of barrier locations were detected due errors in the GIS files, we carefully inspected surface water shape files, digital elevation data, and Google Earth imagery to make corrections. Finally, we used only fragments that had NYDEC fish surveys included since we required both fragment lengths and fish community data.

Fish Survey Data

Fish survey data was obtained from the NYDEC Bureau of Fisheries. The database was in Microsoft Access format and the files included historic, 2006, and 2007 versions. Documentation is included in the metadata of the database. The collections were completed from the mid-1970s to 2006 and varied in their purpose and practices. Electrofishing was routine but some surveys targeted trout and others recorded all fish greater than about 40 mm. Notes were included on sampling purpose, wild and stocked source of captured trout (Family Salmonidae), location, and methods. We considered each sampling report as one collection and did not further define effort or effectiveness because reporting differed in details, methods, and practices.

Statistical Analyses

With a final data set assembled (Appendix 1), analyses were begun by inspecting the distribution of each variable. Stream fragment length was high skewed and transformed by LOG_{10} which made the distribution mode centralized. Fish length variables (average length, minimum length, maximum length, standard deviation of lengths, and length range) were fairly concentrated in the middle of the distribution range so not transformations were applied. The number of species (richness counts, richness per sample) and fish densities (total individuals, individuals per sample) were skewed and transformed by LOG_{10} . Pairwise scatterplots and regression analyses were conducted for each variable and fragment length to test stream landscape theory predictions. The full analysis was repeated without fragments and fish collections that had only stocked trout reported. Only the full data set results are reported here because stocked fish are a persistent part of the fish fauna of the study watersheds. Finally, additional analyses were conducted comparing fragments with and without wild and small young trout to determine if trout reproduction and early survival is linked to stream fragment size.

Principal Findings and Significance

A total of 33 stream fragments were included in the analyses from the Moodna Creek (Figure 1) and Fishkill Creek (Figure 2) watersheds. Fragment lengths ranged from 0.4 km in length to 119 km with a mean length of 20 km. The total number of fish collected in these stream fragments was 1,109 including 22 species. Important sportfish were brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), rainbow trout (*Oncorhynchus mykiss*), smallmouth bass (*Micropterus dolomieu*), largemouth bass (*Micropterus salmoides*), and chain pickerel (*Esox niger*). Other recreational fishing species were bluegill (*Lepomis macrochirus*), yellow perch (*Perca flavescens*), brown bullhead (*Ameiurus nebulosus*), redbreast sunfish (*Lepomis auritus*), and rock bass (*Ambloplites rupestris*). Half of the fishes recorded were non-game species: tessellated darter (*Etheostoma olmstedii*), white sucker (*Catostomus commersoni*), cutlips minnow (*Exoglossum maxillingua*), fallfish (*Semotilus corporalis*), creek chub (*Semotilus atromaculatus*), pumpkinseed (*Lepomis gibbosus*), common shiner (*Luxilus cornutus*), Eastern mudminnow (*Umbra pygmaea*), redfin pickerel (*Esox americanus*), golden shiner (*Notemigonus crysoleucas*), and spottail shiner (*Notropis hudsonius*). The data on stream fragment lengths and fish collections were adequate to test stream landscape theory predictions although we know data sets like this likely have fairly high rates of error.

Predictions 1: Larger stream fragments have more diverse fish communities

Stream fragment size was related to the diversity of fishes collected ($p = 0.0222$, Figure 3) indicating that stream fragments with greater lengths support more types of fish. This was expected because large sections of a watershed offer a greater variety of stream habitats that can support more species with varied environmental requirements. Tests using the number of species per collection was not significant indicating that there was no relation between sampling effort and diversity for the 1 to 5 samples per fragment.

Prediction 2: Larger stream fragments have more diversity in sizes of fish

Stream fragment size was related to average fish size with large fragments having smaller fish on average ($p = 0.0478$, Figure 4). There was no relationship with maximum fish size but there was a significant relationship with minimum fish size ($p = 0.0031$, Figure 5). This pattern of results indicates that large stream fragments are

supporting more young fish and possibly reproduction of the dominant species in the collection: brown trout. We investigate this finding further below.

Prediction 3: Larger stream fragments support greater abundances of fish

This prediction was not supported by the results and analyses. There was no relationship between fish abundance (fish caught by fragment, fish caught by collection per fragment) and stream fragment length. Stocking of the dominant fish reported, brown trout, could be obscuring the expected relation although the same analysis completed without stock-fish-only fragments did not yield a different result. Therefore, we conclude fragment size is unrelated to stream fish abundances.

Trout Reproduction and Rearing Relative to Stream Fragment Length

The findings from our basic prediction tests suggested there are more small trout in large stream fragments. We isolated all stream fragments where wild trout captures were reported and yearling trout were recorded. We considered trout smaller than 150 mm long as wild, stream produced yearling trout because the minimum size of stocked trout is expected to be 178 mm (7 inches). Stream fragments with wild and young trout were larger (t-test, $p = 0.0073$, Figure 6). Almost all large stream fragments were shown to be supporting trout reproduction and rearing while small fragments had no evidence of providing this fish community support function.

Summary of Key Findings

Large stream fragments in the Hudson Valley were found to support more fish species and smaller fish. The abundance of small fish in large fragments corresponds with the presence of young wild trout. This indicates large stream fragments are supporting wild trout reproduction and rearing which would require larger streams for adults and smaller cool streams for reproduction and good early trout survival. Large stream fragments contain a mix of streams connected together providing a range of habitats for completing the life cycle of many stream fish.

Student Support

The following students and learning activities were provided by this project:

Marci Meixler, Ph D graduate in Natural Resources, January 2009

This study in part supported Marci Meixler in her final dissertation work. Her dissertation (Spatial Analysis of Watershed Impairments for Restoration Planning) was related to the study, she completed another Hudson Valley stream analysis at the time, and supplied project data sets and technology.

Catherine Bentsen, BS graduate in Natural Resource, May 2009

Kate Bentsen conducted an independent study as part of the project. Her research report titled 'The Effect of Stream Fragment Length on Fish Population Parameters' used project data and work of the study team.

Michael Wine, BS graduate in Natural Resource, May 2009

Mike Wine was the primary student research intern on this project. He co-authored this report, developed the GIS analyses, assembled fish collection data, and investigated limitations of the source information. Mike also used this work in a class project that resulted in a poster presentation (attached).

Notable Achievements and Awards

Final results of this project were finished for this report. Consequently we have not yet prepared a publishable report of results. However, project students have completed reports and presentations noted above. We are planning to publish the results of this study this summer.

Synergistic Activities

Mark Bain is obligated to give a presentation on stream landscape theory, project findings and the support provided for conservation actions in 2009. This will be planned with Scott Cuppett and possibly other HREP staff. The expectation is a public presentation to watershed interest groups when that can be arranged.

References

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Figure 1. Moodna Creek watershed showing large dams (brown circles), small dams (squares), and fish collections (green dots). Stream fragments used in the study are variably colored and numbered. Stream fragment numbers appear in the data set in Appendix 1.

Moodna Creek

Legend

- dams_moodna
- mood_dams
- moodfish07

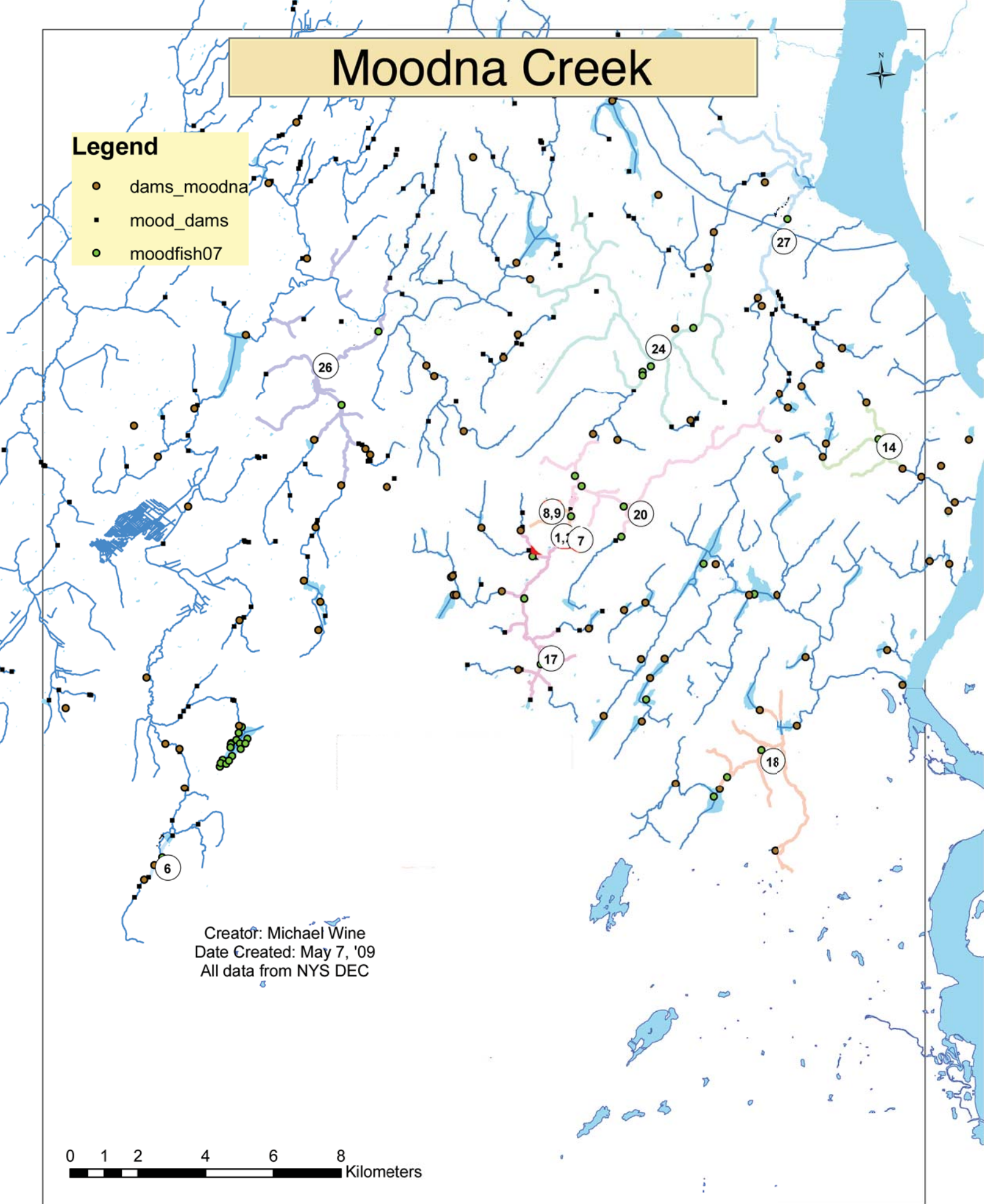


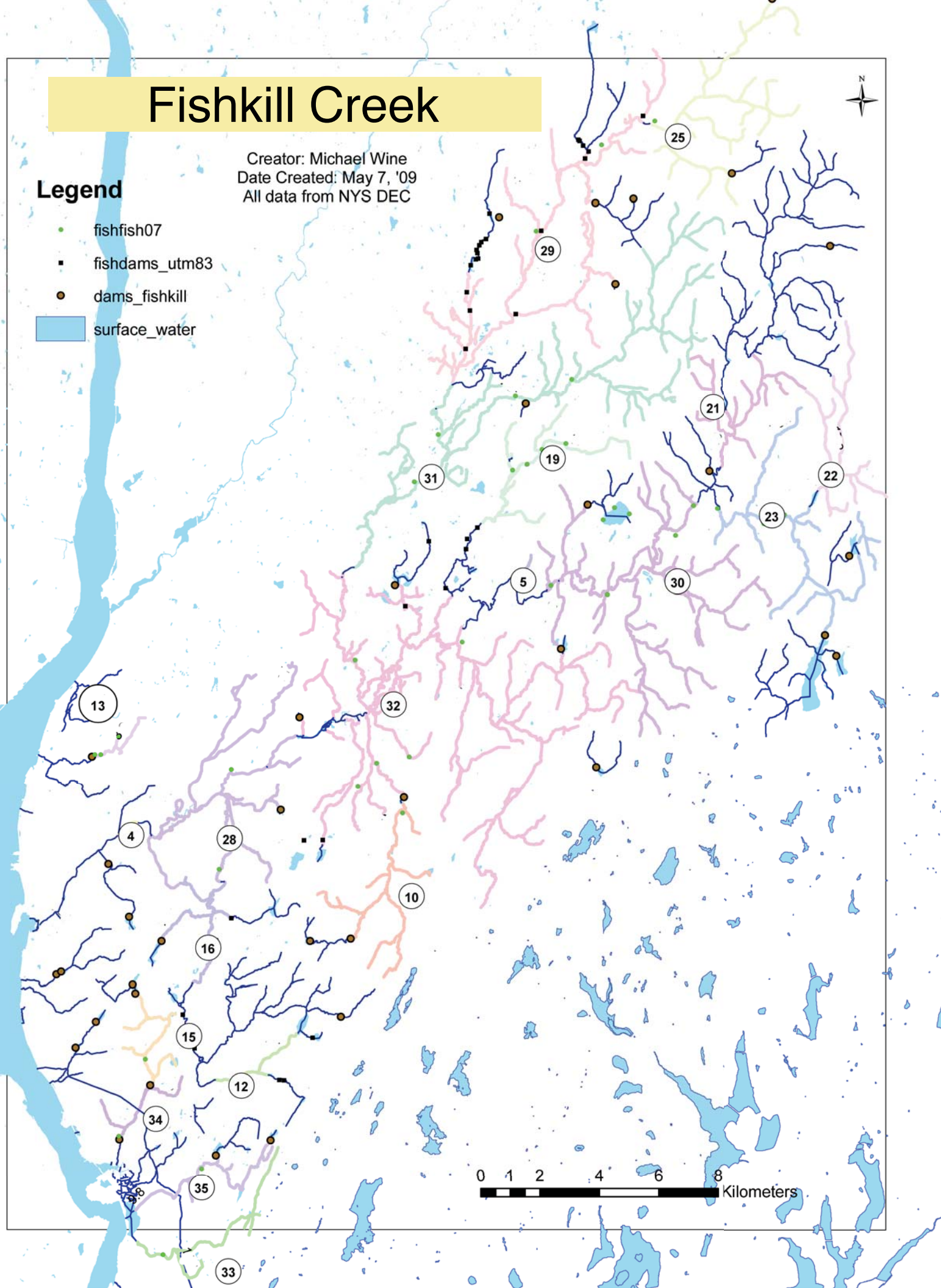
Figure 2. Fishkill Creek watershed and some nearby streams showing large dams (brown circles), small dams (squares), and fish collections (green dots). Stream fragments used in the study are variably colored and numbered. Stream fragment numbers appear in the data set in Appendix 1.

Fishkill Creek

Creator: Michael Wine
Date Created: May 7, '09
All data from NYS DEC

Legend

- fishfish07
- fishdams_utm83
- dams_fishkill
- surface_water



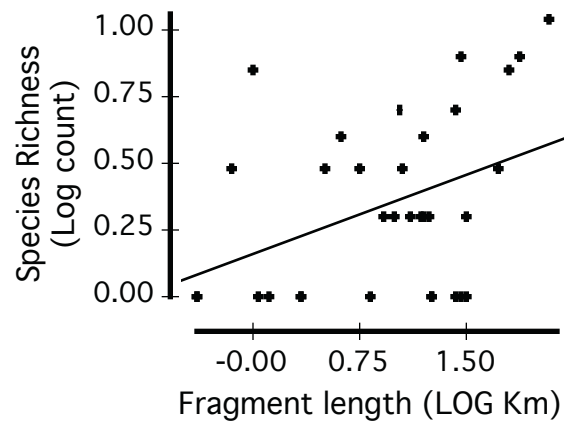


Figure 3. Relation between stream fragment length (km) and the number of fish species recorded in stream fragments. Data are in LOG10 form.

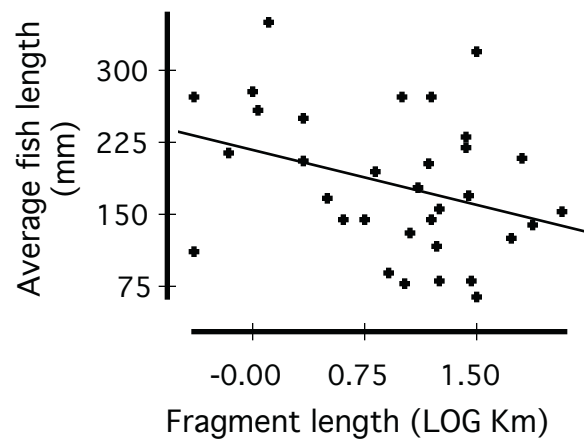


Figure 4. Relation between stream fragment length (km) and the average length (mm) of all fish recorded.

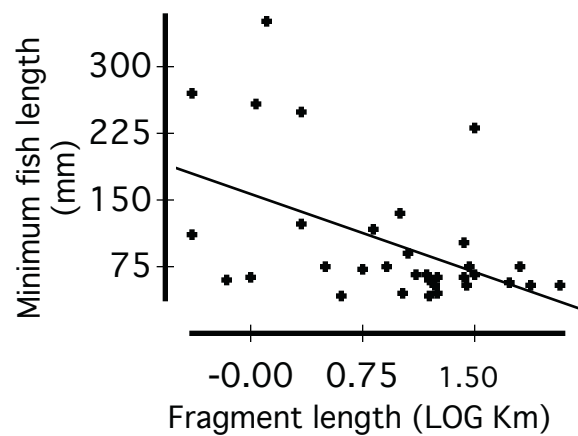


Figure 5. Relation between stream fragment length (km) and the minimum length (mm) of all fish recorded.

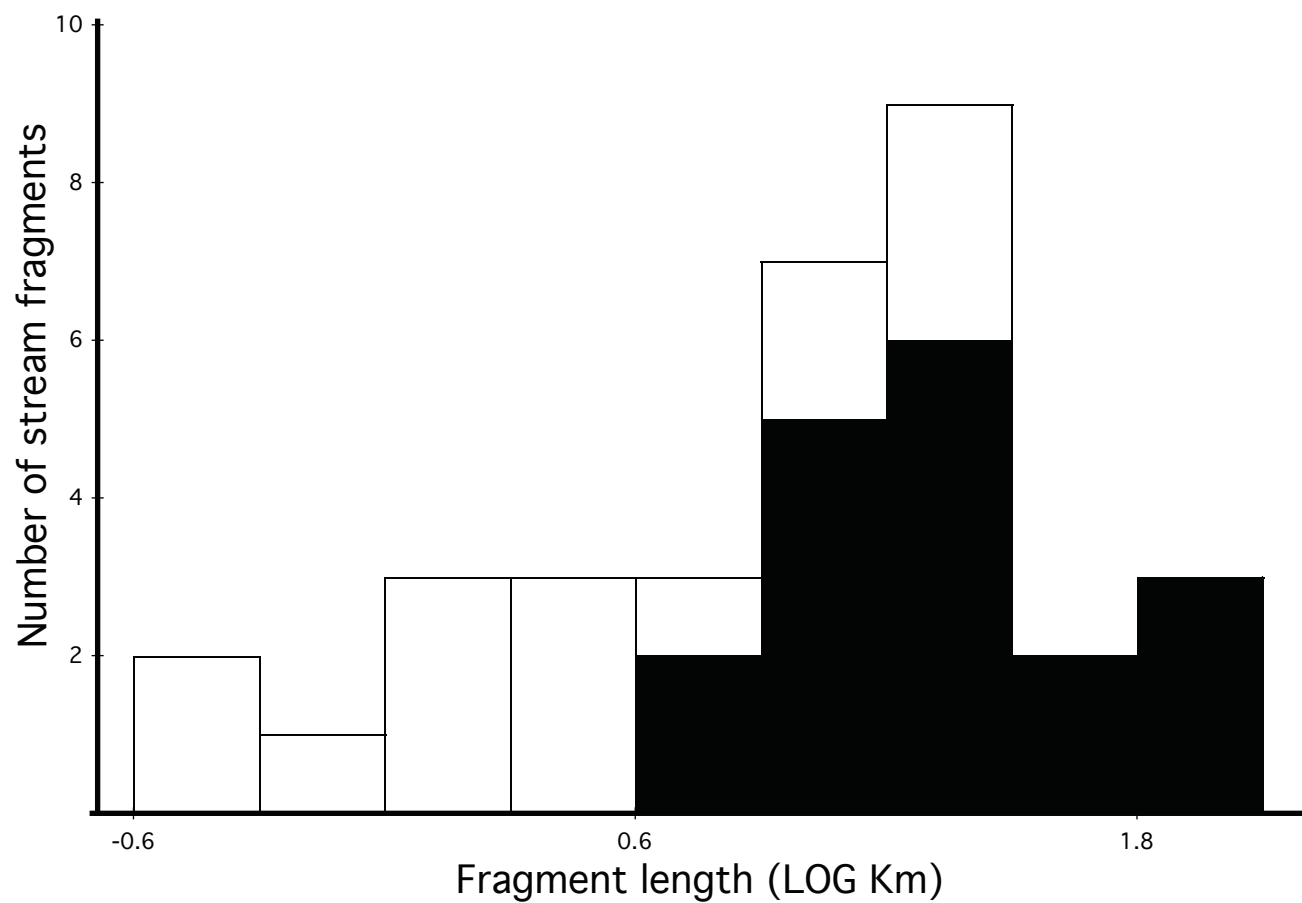


Figure 6. Distribution of stream fragments supporting trout reproduction and yearling rearing (shaded) and those stream fragments not supporting wild trout production (unshaded).

Appendix 1.

Final data set with stream fragment identification numbers in the first column.

ID#	Stream basin	length (km)	Average fish length (mm)	Std Deviation fish length (mm)	Minimum fish length (mm)	Maximum fish length (mm)	Numer of Unique Species	Number of fish caught	Number of collections	Fish species in rank order	Notes on Wild Trout present
1	Moodna	0.4	112.0	0.0	112	112	1	3	1	Brown trout	
2	Moodna	0.4	271.0	0.0	271	271	1	62	1	Brown trout	
4	Fishkill	0.7	214.4	56.6	60	272	3	15	1	Brown trout, 1 of bluegill, tessellated darter	Wild, No young
5	Fishkill	1.0	276.6	96.5	64	428	7	45	1	White sucker, brown trout, cutlips minnow, largemouth bass, 1 of smallmouth bass, bluegill, fallfish	
6	Moodna	1.1	257.0	0.0	257	257	1	49	1	Brown trout	
7	Moodna	1.3	351.0	0.0	351	351	1	51	1	Brown trout	
8	Moodna	2.2	205.7	54.7	124	287	1	44	3	Brown trout	
9	Moodna	2.2	249.0	0.0	249	249	1	44	1	Brown trout	
10	Fishkill	17.9	155.4	85.0	46	394	1	19	1	Brown trout	Wild & Young
12	Fishkill	4.1	145.5	67.4	41	237	4	20	1	Brown trout, creek chub, 1 of yellow perch, brook trout	Wild & Young
13	Fishkill	3.2	166.3	105.1	75	450	3	26	1	Bluegill, largemouth bass, brown bullhead	
14	Moodna	6.7	194.6	53.7	116	226	1	7	2	White sucker	
15	Fishkill	8.2	88.4	13.5	74	115	2	12	1	Brown trout, pumpkinseed	Wild & Young
16	Fishkill	10.6	76.4	37.9	46	168	5	18	1	Brown trout, common shiner, cutlips minnow, 1 of fallfish, creek chub	Wild & Young
17	Moodna	12.9	178.4	81.3	66	258	2	48	3	Brown trout, E mudminnow	
18	Moodna	15.1	202.5	67.4	65	230	2	6	2	Brook trout and 1 common shiner	
19	Fishkill	15.6	144.7	38.4	41	224	4	27	4	Brook trout, creek chub, pumpkinseed, 1 common shiner	Wild & Young
20	Moodna	15.9	272.6	154.3	61	390	2	92	4	Brown trout, tessellated darter	Young, Wild
21	Fishkill	18.0	79.5	24.7	62	97	1	2	1	White sucker	
22	Fishkill	17.1	117.0	89.1	54	180	2	2	1	1 of white sucker, brook trout	
23	Fishkill	26.7	218.6	100.7	63	478	5	28	2	Brown trout, fallfish, redbfin pickerel, 1 of chain pickerel, bluegill	Wild & Young
24	Moodna	26.6	229.5	36.6	102	265	1	66	5	Brown trout	
25	Fishkill	29.6	79.7	5.6	74	87	1	7	1	Brook trout	Wild & Young
26	Moodna	31.0	319.6	50.1	230	342	2	5	2	Rainbow trout, redbfin pickerel	
27	Moodna	31.9	65.0	0.0	65	65	1	9	1	Brown trout	Wild & Young
28	Fishkill	28.4	169.1	84.1	54	369	8	34	2	Brown trout, white sucker, redbreast sunfish, rock bass, fallfish, smallmouth bass, 1 of creek chub, common shiner	Wild & Young
29	Fishkill	53.4	124.0	76.2	57	314	3	51	2	Brown trout, pumpkinseed, golden shiner	Wild & Young
30	Fishkill	63.1	208.9	49.6	75	353	7	64	4	Brown trout, bluegill, largemouth bass, 1 of rock bass, common shiner, pumpkinseed, white sucker	Wild & Young
31	Fishkill	76.1	138.1	67.0	55	298	8	173	4	brown trout, pumpkinseed, tessellated darter, bluegill, largemouth bass, 1 of redbfin pickerel, rock bass, yellow perch	Wild & Young
32	Fishkill East of	119.3	153.9	78.8	55	375	11	38	5	brook trout, brown trout, creek chub, redbfin pickerel, 1 of bluegill, white sucker, golden shiner, largemouth bass, rock bass, cutlips minnow, spottail shiner	Wild & Young
33	Hudson East of	11.1	131.9	58.4	91	280	3	10	1	brown trout, 1 of pumpkinseed, creek chub	Wild & Young
34	Hudson East of	5.7	145.6	78.7	72	335	3	27	1	brown trout, white sucker, 1 of pumpkinseed	Wild & Young
35	Hudson	9.8	272.6	81.0	134	347	2	5	1	brown trout, 1 yellow perch	Wild & Young

Attachment

Poster display prepared by Michael Wine.

Effects of fragment size on fish abundance and diversity in Moodna and Fishkill Creeks

By Michael Wine

Introduction:

Fish populations are affected by land use change, invasive species, stocking, and dams. High dams impound large areas of water and prevent upstream fish passage. Most dams in the Moodna and Fishkill watersheds lack fish ladders. Impounded water may have lower oxygen concentration and different macroinvertebrate communities than free flowing streams. Ph can also be affected in impounded areas. Water temperature and hydrologic regime may be affected downstream of dams. Water quality standards are more likely to be met in flowing streams than in impoundments. These aforementioned issues related to impoundments have been well studied. However, less work has been done to quantify the relationship between stream fragment size and fish diversity and abundance.

There are several reasons why one might expect greater fish diversity in larger fragments. Every fragment contains degraded areas above and below dams. However, a smaller fraction of the length of the stream channel is likely to be degraded in larger fragments. (Within a fragment parts of the stream channel may be degraded for reasons other than dams, but these are not the topic of this study.)

In larger fragments fish can migrate within a fragment. Since fish are stenothermic they must change their location to control their temperature and survive. They must also be able to migrate to the best foraging areas, spawning grounds, shelters, and over-wintering areas. Furthermore since fish diets change throughout the lifecycle of each species, a fragment must contain all of the habitats necessary for the entire lifecycle of a fish.

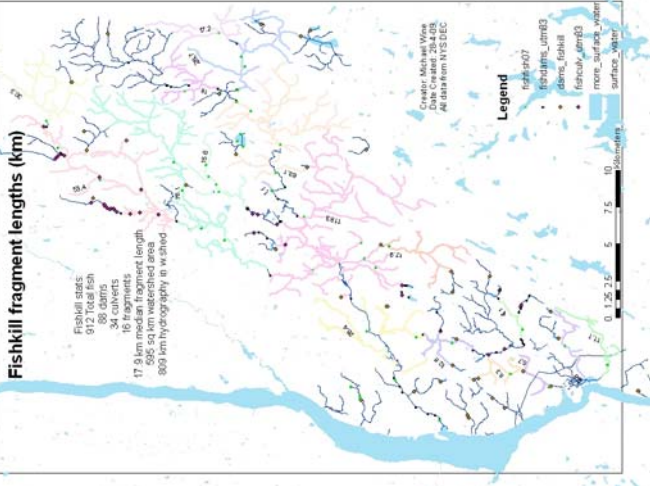
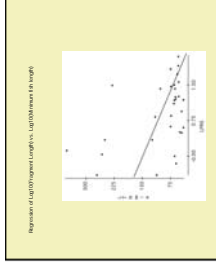
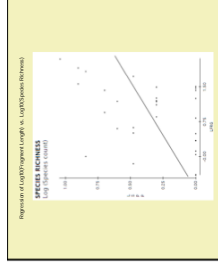
In larger fragments there is a wider range of habitat availability. One fragment may contain first through fourth order streams. This wide variety of habitat could allow fish to escape rare events such as unusually high or low flows. A wide range of habitat would be expected to have a wide range of small fish species. More small fish in a fragment could improve the diversity of large piscivorous predators.

Often there are dams upstream of the fragment. Fish may flow over these dams especially during peak flow events. Large fragments may have more upstream dams that can serve as a source of fish than smaller fragments. The section of the Hudson where Moodna and Fishkill flow in ranges from freshwater to oligohaline depending on the season.

Methods:

Editor tool in ArcGIS 9.3 was used to split, merge and measure the hydrography of Moodna and Fishkill creeks. Fragments were only measured where they did not contain migratory fish from the Hudson River and where fish collections were collected in a lotic environment. A linear regression was used to determine the relationship between fragment length and standard deviation, minimum, maximum, average and range of fish length. Number of fish, species richness and collections per fragment were counted from NYSDEC fish collection data. In Moodna watershed most elements lined up well with the hydrography. In Fishkill one dam shape file contained many points that were not properly positioned. Surface water shape files, DEM's and Google Earth were used to estimate the actual location of certain dams in this watershed.

Fragments were defined as the length of the stream between dams. In some cases this is a short reach of channel; in other cases fragments are made up of large dendritic segments. Within a fragment impounded sections of the stream were subtracted from the total fragment length unless Google Earth showed a lotic environment. Culverts and waterfalls were disregarded and dams were not analyzed to determine if they were in fact barriers to fish passage.



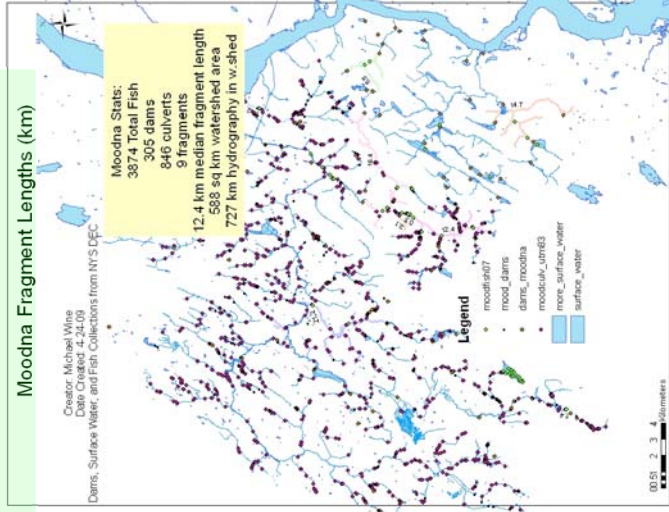
Results and Discussion:

There was a negative relationship between log of fragment size and the minimum size and average size of fish in the fish collection (p value = 0.00885). This could indicate that there is greater reproduction in larger fragments. The small fish that drove this trend were brown trout. In small fragments stocked fish made up the majority of the collections; thus if fish weren't stocked then very few would naturally inhabit these fragments.

There was a positive correlation between species richness and fragment length (p value = 0.00968). This positive correlation does indicate that a greater species richness was observed in larger fragments, however to know definitively if there is greater species richness in larger fragments equal sampling effort would be required in each fragment size.

There are several ways to improve this study. Only fish greater than 50 mm were collected, thus small species were not measured. Collections were concentrated near roads rather than randomly placed and many were sampled in lentic areas. It would be beneficial to have more collections. Catch per unit effort could not be calculated because several different gears were used. Many of the coordinates did not fall directly on the hydrography; improved GPS coordinates would benefit future studies. DEC sampling crews may have gravitated toward sites where stocked fish were present.

In future studies it would be beneficial to have a list of every dam, culvert and waterfall and analyze these to determine their barrier potential. Another future research question could address how land cover near these watersheds affects the fish therein.



Potential impacts of climate change on sustainable water use in the Hudson River Valley

Basic Information

Title:	Potential impacts of climate change on sustainable water use in the Hudson River Valley
Project Number:	2008NY112B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	14
Research Category:	Climate and Hydrologic Processes
Focus Category:	Hydrology, Management and Planning, Models
Descriptors:	None
Principal Investigators:	Allan Frei

Publication

PROGRESS REPORT
Potential Impacts of Climate Change on Sustainable Water Use in the Hudson River Valley
May 1, 2009

A grant to:
The CUNY Institute for Sustainable Cities (CISC)

Funded by:
Water Resources Research Grant Program FY2008 New York State Water Resources Institute (WRI)
New York State Department of Environmental Conservation
and Hudson River Estuary Program

With Support from:
City University of New York (CUNY)
CUNY Institute for Sustainable Cities (CISC)
Orange County Water Authority (OCWA)

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PRELIMINARY Summary and Conclusions

***NOTE: these conclusions will be reviewed and updated before submission to OCWA**

The purpose of this project is to help the Orange County Water Authority (OCWA), as well as other Orange County government departments, to begin to include the potential impacts of climate change in their long-term water planning. We have generated a review of published information that is pertinent to OCWA's long range water planning activities, performed some additional technical analyses, begun outreach activities within Orange County, and articulated a number of preliminary recommendations for OCWA. After we review and refine these recommendations, the next step is to submit our report to OCWA, and to work with OCWA to determine how best to use this information, and how to continue outreach activities, to most effectively serve the interests of Orange County.

The conclusions of this report reflect the current understanding of how the human impact on climate may change in the future. In the coming years, the results used to derive these conclusions may change for two reasons. First, it is possible, although unlikely, the the uncertainty around climate change predictions will significantly decrease due to improved physical understanding of the climate system and more accurate models. The more likely reason that the conclusions might change is that, as time progresses, we will know with more certainty the magnitude of human greenhouse gas emissions, and will have more evidence as to the potential impacts of those changes. For example, the scenarios used to portray possible global greenhouse gas emissions were developed ten years ago. The actual global emissions that have occurred since then are, according to experts, actually greater than the "high emission" scenarios used in these analyses.

Thus, our conclusions, based on the best available scientific understanding, are the following:

- *Temperature and Precipitation Change in the Hudson River Valley by the End of the 21st Century.* There is complete agreement amongst models that temperatures in this region will increase, and reasonable agreement on the range of temperature changes that might be expected. However, there is less agreement on the magnitude, and even on the direction, of precipitation changes. It is likely that precipitation will increase, but it may also decrease significantly. It is likely that, regardless of any change in total precipitation, a greater proportion of precipitation will fall in larger events.
- *Surface Water Availability and Seasonal Streamflow Cycle by the End of the 21st Century.* Under the most likely (67%) sceneario, the mean annual surface water availability will not change significantly. However, due to the uncertainty in precipitation changes, there is a smaller but still significant possibility that water supplies will change appreciably, either increasing or decreasing. Changes to the seasonal stream flow timing are likely to be minimal compared to more snow-dominated regions because in the Hudson River Valley snow does not dominate the annual water cycle. Lower groundwater levels, however, may reduce baseflow to streams significantly.
- *Soil Moisture, and Ground Water by the End of the 21st Century.* Soils will almost certainly be drier, possibly much drier. Groundwater levels, like soil moisture, are expected to be lower. At the upper bound of the "most likely" (67%) range of scenarios, mean soil moisture and mean ground water levels may not change significantly. At the lower bound of the "most likely" (67%) range of scenarios, mean soil moisture and mean ground water levels may be diminished by up to 25%.
- *Extreme Events and Droughts by the End of the 21st Century.* It is extremely likely that the frequency of temperature extremes will change, with more hot days and fewer cold days. Under some scenarios, by the end of the century the summer climate of this region will resemble the southeastern US. The frequency of droughts in this region is unlikely to decrease, and may not change at all. However, if precipitation decreases, the frequency of droughts in this region may rise appreciably.

- *Outreach Conclusions.* The Orange County students who participated in the preparation of outreach materials showed great enthusiasm and interest in this subject. Although our wider outreach effort has not yet started, we expect that the interest on the part of a wider audience in Orange County will be similar. Upcoming outreach events include the annual Orange County Earth and Water Festival, a public education event being sponsored by OCWA and the County on June 13, at which a poster about this study will be featured and the project will be tentatively be included in an educational presentation about OCWA projects and programs. Findings of this study will also be used in development of educational presentations designed for elected officials, planning board members, and other municipal decision-makers, and for other adult audiences, an OCWA project currently underway.

PRELIMINARY Recommendations for Orange County

***NOTE: these recommendations will be reviewed and updated before submission to OCWA**

The recommendations listed here are considered preliminary, in the sense that the final recommendations will depend on further discussion with OCWA about the results of this report. However, we feel that providing these preliminary recommendations can serve as a starting point for discussions.

- *Evaluate Water Demand Projections.* At the lower end of the most likely (67%) scenario, surface water resources available to OC will not change dramatically, but soil moisture and groundwater resources will be diminished. Development plans must consider the potential diminishment of these resources.
- *Maintain Familiarity with Major Climate Change Studies.* Every five to seven years an updated IPCC assessment is produced. Periodically, other regional analyses might become publicly available. It would seem prudent of OCWA to keep abreast of the major results of these reports, which will allow OCWA to keep their plans flexible in the face of uncertainty.
- *Keep Plans Flexible.* While surface water availability may increase or decrease depending on how precipitation changes, soil moisture and groundwater resources may be significantly diminished. Plans for development must remain flexible in terms of supply and demand in order to account for the uncertainties.
- *Maintain links to Regional Partners.* In the case of diminished water supplies, one strategy for flexibility is the possibility of shared water resources with other regional municipalities. This would involve shared risks as well as shared responsibilities.
- *Consider Effects of Extreme Events and Higher Temperatures on Water Quality.* Regardless of whether the total water supply changes, it is likely that OC surface water resources will experience a higher proportion of large precipitation events, and likely that water temperatures will increase. The potential implications for water quality, as well as ecological services, should be considered.
- *Continue Monitoring.* It seems prudent for OC to fund appropriate monitoring networks for water supply and stream flow. This will allow the county to accurately assess any changes that might occur during the coming decades. Monitoring water quality in streams is also important, because changes in precipitation patterns may cause increased runoff and erosion rates, thereby affecting water quality through increased sedimentation and other effects.
- *Conduct Historical Analyses.* The technical analysis performed for this report uses data from the Moodna Creek Watershed, which is available for only the last 10 years. In general, this is too short a time period for climatological analyses. The basic conclusions of this report would not change if we had a longer record. However, there are good reasons to reconstruct what happened during earlier decades. For example, in the absence of a continuous, ongoing, reliable stream gauge record in OC, it is impossible to estimate what the true historical seasonal cycle, or total annual stream flow, actually was because the last 10 years may not be representative of earlier decades. Also, we can not gauge how future changes might compare to historical precedents. How do the different dry scenarios for this century compare / contrast with the record drought of the 20th century that occurred in the early-mid 1960s? Frei has begun to investigate the possible use of the water balance model to estimate historical conditions. It would be fruitful to continue this investigation. Details can be provided if OC is interested in pursuing this.

Introduction

This document serves two purposes. First, it is the annual report to WRI, the primary granting agency on this project. Second, this document will be reviewed and updated, and subsequently submitted to the Orange County Water Authority (OCWA), who is the main benefactor of this project. Subsequent to OCWA's receipt of this report, the project participants will meet with OCWA to decide how to proceed in the best interests of Orange County. Without the active participation of OCWA and / or other Orange County stakeholders, this project will not be successful. We have generated a review of information that is pertinent to OCWA's long range water planning activities, performed additional technical analyses specifically for this project, begun outreach activities within Orange County, and articulated a number of recommendations for OCWA (all of these are discussed in this report). The next step is to work with OCWA to determine how best to use this information, and how to continue outreach activities, to most effectively serve the interests of Orange County.

Problem Statement and Research Objectives

The problem that is addressed by this grant is that the municipality of Orange County, New York, is beginning to include the potential impacts of climate change in their long term water resource planning, but does not have the in-house technical expertise to review and interpret the current state of knowledge on climate change. They have hired outside consultant to partially address this issue, and this project is complementary to the consultants' work. To address this problem, we have identified three objectives. (1) The primary objective of this project is to provide to the Orange County (OC) Water Authority (OCWA) assistance *that they identify as necessary to begin* to include climate change in their planning process to meet their long-term water supply objectives. The goal is to ensure that plans include sufficient flexibility so that the community is prepared for, and can adapt to, climate change. (2) The second objective is to work with OC to perform outreach, which would help generate interest, disseminate information, and encourage input from OC residents in this process. (3) The third objective of this project is to use our experience with Orange County to develop materials that might be useful to other regional stakeholders, and to develop additional regional collaborations to continue this work, if appropriate, after the terms of this project have been completed.

Methodology

The methodologies used in this study relate to technical issues, as well as to non-technical outreach related activities. The main technical methods are to work with OC to identify what information about climate change is required by OCWA, to determine what format that information can most easily be used by OC, to determine whether or not that information is available, and to provide guidance for the use and interpretation of climate-related information. The first step is to identify publicly available information, including previous or on-going research reports that may be useful in that regard (table 1). The second step is to provide interpretation of the publicly available technical information so that it is useful to OC. The third step is to perform an additional technical analysis, as identified in the project proposal, that is required to help OCWA in this regard. Our results will be presented to OCWA in the near future, at which time the participants will discuss with OCWA exactly what OCWA needs in order to benefit as much as possible from this project.

The first outreach methodology is to engage environmental study students at SUNY Orange, a community college in OC, in projects designed to disseminate information about this issue: that is, for the students to develop outreach materials. Professor Joseph Zurovchak, a co-author of this report, teaches this class. During the spring 2009 semester he had students prepare outreach materials that are to be presented at different forums. Materials include pamphlets, electronic presentations for oral delivery, podcasts, webpages, and local newspaper pieces. The figures and other materials included in student projects include either general information from class or outside sources, or specific information supplied by this project. The information supplied by us comes from our own technical analysis as well as the sources outlined in table 1 and discussed below. Students will make these materials available to the SUNY Orange community, public schools, and the county public in general. We hope to make many of these outreach materials public at the OC Earth and Water Festival on June 13. Also, podcasts and possibly other material can be hosted at CISC's web site. Other opportunities will be considered as well.

The second outreach methodology involves student outreach assistants hired under this grant to prepare and distribute outreach materials. Recruited from both Orange County and CUNY, where the Institute for Sustainable Cities is hosted, these students will work to create the final outreach products of this project, aiding in all phases of the material production from inception to production. Student Outreach Assistants will gather information from stakeholders, end users, SUNY Orange students, and project staff to understand the preferred format for educational materials. They will then be responsible for creating these materials, presenting them and finally disseminating them. Other team members will of course be involved in the process, but students will take the lead.

Principal Findings and Significance

Identification of Publicly Available Information A number of previous or ongoing research projects and reports about climate change in this region (table 1) provide a great deal of information that may be relevant to Hudson River Valley communities such as OC. These results should provide a comprehensive picture of what is known about climate change in this region. In this section we summarize the results that are most relevant to OC from each source listed on table 1.

NYS DEC Climate Literacy Points (table 1, #1) The New York State Department of Environmental Conservation (NYSDEC 2009) recently promulgated a document identifying the key concepts required for climate change literacy, as well as some resources for more information. This document has been thoroughly vetted by DEC, and the authors of this report agree with DEC that it is a concise, accurate summary. It is not specific to NY State. The full content of this document is included in Appendix A of this report.

IPCC (table 1, #2) The IPCC is the internationally accepted organization for the global consensus of the current understanding of climate change. IPCC documents address the issue of climate change from the global perspective, but also show selected regional results. The document referred to in this report (Bates et al. 2008) summarizes the most recent IPCC findings that relate to water resources. An important take-home message from the perspective of OC is that, although there is good agreement amongst models on the range of temperature changes that might be expected, there is relatively poor agreement between models, and therefore significant uncertainty, on water cycle changes at local and regional scales, including in the Hudson River Valley. In the Hudson River Valley region, at least 80% of models indicate an increase in total annual precipitation, and in winter precipitation. In this region (and across most of the Northern Hemisphere) there seems to be good agreement that, regardless of whether total precipitation increases or decreases, the portion of precipitation coming from very large events will increase. However, there is less than 80% agreement in this region on whether we will see increased or decreased summer precipitation, mean annual soil moisture, or total annual runoff. This point bears repeating and emphasis: *for many aspects of the water cycle, there is less than 80% agreement amongst models on whether these values will increase or decrease.*

NECIA (table 1, #3) The NECIA report (NECIA 2006) has a regional focus on the northeastern U.S., and it provides some results that are relevant to OC water supplies. To demonstrate the dramatic potential for summer temperature changes, NECIA developed “climate migration” maps for various locations, including one for southeastern New York State (figure 1). NECIA indicates that by the end of the century the heat index of summers in southeastern NY State may be similar to the current climate of the South Carolina / Georgia region. The potential for droughts may be considerably increased under warmer conditions, depending on if / how precipitation changes. Figure 2 shows results from three models, with two specific greenhouse gas emission scenarios, of the number of droughts of different durations to be expected. Although these should be considered only sample scenarios, as they do not necessarily reflect the full range of possibilities, they are instructive. Under the low emission scenario there is no expected change in the frequency of either medium length droughts (duration of 3-6 months), which have been rare during the last 30 years, or longer droughts (duration greater than 6 months), which have not occurred in this region in the last 30 years. However, under the high emissions scenario,

both medium length and longer droughts might be expected. The question of how these droughts might compare to the early-mid 1960s, when this region experienced the most significant long-term drought of the last century, was not discussed.

NPCC (table 1, #4) The NPCC report (NPCC 2009) summarizes what is known about climate change and adaptation with the specific focus on New York City. Many of these results should in general be applicable to OC. Although the magnitude of the warming is expected to increase northward and inland from the city, the differences between New York City and OC should be within the uncertainty range. Figure 3 shows that all models predict a warming in this region, with 67% of the models falling between 4°F and 7°F, but some models indicating a warming of greater than 7°F. Figure 4 shows that the disparity in precipitation estimates is quite wide for this region. 67% of the models suggest a precipitation increase between 4% and 7%. Some models suggest an even greater increase in precipitation, while others suggest a decrease of up to 10%. Figure 5 contains a portion of a table from the NPCC report showing the expected change in the frequency extreme temperature and precipitation events between now and the end of the century. It is clear that OC should expect a greater number of very hot days and fewer very cold days. However, changes in total precipitation and drought frequency are more uncertain. Note, however, that it is much more likely that the frequency of droughts will either increase or remain approximately the same, and not at all likely that the drought frequency will decrease.

OCWA (table 1, #5) The OCWA Draft Water Master Plan, Task 2: Strategic Plan, dated March 2009, is available to us at the time of this writing. Section 3.3.3 contains a summary of a report prepared by consultants hired by OCWA which addresses the potential impacts of climate change on water supply. We find it to contain an excellent literature review and analysis. The information provided by this project should be complementary to consultants' analysis. The information from the sources outlined in table 1, and the technical analysis described in the next section, may provide more details and specific ranges of uncertainty that may be useful to OCWA.

NYSERDA (table 1, #6) The New York State Energy Research & Development Authority (NYSERDA) *Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State* is a project, which is in progress at the time of this writing, that includes researchers from across NY State. The goal is to evaluate the state's prime vulnerabilities to climate change. The final NYSERDA findings have an expected publication date in 2009. One of the main sectors examined by NYSERDA is "water resources", in which Frei is a participant. It is expected that OC will be mentioned in that report as a case study of a county that is taking appropriate action to include adaptation to climate change in the long term plans. The NYSERDA findings should be helpful to OC because the report may result in funding opportunities for resources to help municipalities across the state.

NYCDEP (table 1, #7) The New York City Department of Environmental Protection (NYCDEP) *Integrated Modeling Project* is a major initiative to perform a comprehensive analysis of the vulnerabilities of the NY City water supply system to climate change. This includes the development a suite of quantitative analyses and modeling capabilities to estimate the potential changes on water quantity and quality available to the city's reservoir system, which is located primarily in the Catskill Mountains north of OC. This project began in late 2008 and is expected to last four years. DEP is working in conjunction with CUNY on this project, and Frei is the CUNY Primary Investigator. DEP is eager to have their results and products be applicable to other municipalities in NY State. Thus, it is likely that some of their results, and perhaps computer simulation programs, may be useful to OC, and perhaps to other municipalities, in the future. It is currently too early in the project for any results.

Technical Analysis Performed for this Project The technical analysis performed for this study entails the application of a water balance model to estimate the current mean hydrological cycle and potential impacts of climate change in the Moodna Creek watershed, which is considered representative of OC surface water resources. This step is required for two reasons. First, because there are currently no active stream gauges in OC, and therefore no reliable information on the annual cycle of streamflow, soil moisture, or other hydrological

variables. Second, because such a model is required to estimate the potential changes in the water balance associated with different scenarios of climate change. Meteorological data from Black Rock Forest (BRF, located in OC, in the Moodna Creek watershed) is available for the last decade or so, and is being used to drive the model, which produces estimates of monthly and annual mean values for streamflow, snow cover, and other hydrological parameters. The model has previously been used for studying climate change impacts on New York city water supplies from the Catskill Mountains (Frei et al. 2002). Note that this model is most appropriate for climatologically mean results, not extreme conditions such as droughts and floods. Figure 6 shows preliminary model results for mean monthly streamflow and snow cover during the period of overlap between the BRF meteorological station and ancillary data used to verify that model results are realistic. These results indicate that the model is providing a valid simulation of the mean hydrological cycle in the basin.

Figure 7 shows the estimated monthly mean streamflow (left panel) and soil moisture (right panel) for Moodna Creek under current (1997-2008) conditions (black line). In addition, the “most likely” (67%) range (red), and full range (orange), for the 2080s are shown. These ranges correspond to the temperature and precipitation ranges identified for NY City in the NPCC analysis (figures 3 and 4 of this report). This analysis indicates a number of points. (a) In the most likely scenario, Moodna Creek stream flow will not change much because increased precipitation will offset increased evaporation associated with warming. However, even a small percentage decline in available water (within the “most likely” range) can be important if population / demand increases. (b) It is less likely, but still possible, that a significant change in surface water availability will occur, which could entail either an increase or decrease, depending on how precipitation changes. (c) It is most likely that soil moisture, as well as groundwater (not shown), will decrease, possibly significantly. It is less likely that soil moisture as well as groundwater will increase, and if they do increase, it will only be incrementally.

Figure 8 shows results for the Canonsville Reservoir in the nearby Catskill Mountains. Annual mean changes in the Moodna are comparable to the Catskills. However, the potential impact of climate change on the seasonal streamflow cycle are much less dramatic in the Moodna because it is much less snow-dominated than the Catskill Mountains. This can be seen by comparing the projected spring and winter streamflow changes. In both the Catskills and the Moodna, spring stream flow is diminished and winter stream flow increases, but the magnitude of the potential shift is much greater in the Catskills.

In contrast to the method employed here, the consultants for the *OCWA Draft Strategic Plan, Task 2* (table 1) use a set of actual scenarios from several climate models, and use a monthly water balance program provided by the USGS. Their analysis is very useful and accurate. We chose to use the range of results from climate models because no specific scenarios can capture the full range of potential temperature and/or precipitation changes expected by all plausible scenarios. This sort of analysis is consistent with a great deal of current literature suggesting that, for adaptation purposes, such a technique is probably more appropriate (Dessai et al. 2009). Also, our water balance model is run on a daily time step (although the results are reported in monthly values). This is advantageous when calculating the snow melt, and when calculating the portion of water that is retained in the soil versus the portion that contributes to runoff, and thus may provide a more realistic simulation of the seasonal hydrologic cycle. Annual mean results should be similar between the two models.

Non-technical Objectives

The non-technical objective involves outreach, including OC residents as well connecting with other Hudson River Valley stakeholders for potential collaborations. Students from Dr. Zurovchak's Spring 2009 Environmental Conservation course at SUNY Orange are producing outreach materials to deliver to various public sectors, including the campus community at SUNY Orange, local elementary and high schools, the general public within the region via a newspaper segment, and the public at large via the internet.

Gruber will be working with the Network members to disseminate technical findings and outreach materials to key stakeholders in the region, and to seek additional opportunities to present this information at meetings and conferences in 2009. The materials that we are producing are relevant to Hudson River Communities in general. We plan to evaluate potential outreach opportunities.

Student Involvement and Support

This project involves significant student involvement and support. As part of our outreach activities, the twenty students comprising Dr. Zurovchak's Spring 2009 Environmental Conservation course at SUNY Orange created outreach materials to deliver to various audiences (e.g., college campus, area public schools, web pages). In addition, three student employees are part of this project: one research assistant, and two outreach assistants. The research assistant, ShihYan Lee, who is a co-author of this report, supported the technical portion of this report, including data analysis, computer modeling, and preparation of figures. The two outreach assistants will be hired as summer employees to use the materials that have been compiled from the sources listed on table 1, additional material developed as part of the technical analysis of this project, as well as the outreach materials developed by SUNY Orange students. They will assist us in developing outreach materials that can be useful to Orange County as well as to other regional municipalities.

Notable achievements and Synergistic Activities

Preliminary results of this project were presented at a meeting of Hudson River Valley Climate Network, on February 4, 2009. At this meeting, a number of NY State DEC employees, as well as representatives from OCWA, and from other regional stakeholders, were present. It is hoped that some of the connections made at that meeting will allow us to develop future regional collaborations. As a result of those connections, the CUNY Institute for Sustainable Cities has already hosted a meeting of the NY State Sea Level Rise Task Force.

Results of this project are intended to be included as a case study in the final report of the *NYSERDA Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State* (expected publication in 2009) (Frei is a participating scientist in the NYSERDA project). This document will serve as a guide for future activities for NY State in the area of climate change adaptation.

And, perhaps most importantly, it is hoped that the results of this project will be incorporated into Orange County's long term water planning process. This will be discussed with OC officials in the coming months.

Finally, Frei is working as the Primary Investigator on two contracts between the CUNY Institute for Sustainable Cities and the New York City DEP on their *Integrated Modeling Project*. This project involves two 4-year contracts to hire a total of seven post-doctoral researchers to develop a suite of quantitative analyses and modeling tools to allow NY city to evaluate the potential impacts of climate change on the quantity and quality of the NY City water supply system. The first contract has been in effect for several months, and two of the post-doctoral researchers have already started working. The second contract, and remaining researchers, will begin in 2009. Frei has discussed with the DEP project manager the possibility of using results of the DEP project to support the efforts of other NY State municipalities in their climate change adaptation activities. DEP has expressed an eagerness to make their work available in that regard.

PROJECT / REPORT NAME	DESCRIPTION
1. NYSDEC (NYSDEC 2009) New York State Department of Environmental Conservation (NYSDEC) Climate Literacy Points	A short document prepared by DEC which summarizes the main points that are understood about global climate change. Not specific to NY State.
2. IPCC ³ (Bates et al. 2008) Climate Change and Water, Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report Technical Paper VI, 2008	This report pulls together all the information that is relevant to water resources from the most recent (2007) IPCC analyses.
3. NECIA ² (NECIA 2006) Report of the Northeast Climate Impacts Assessment (NECIA) Climate Change in the US Northeast, 2006	A report sponsored by the Union of Concerned Scientists which analyzes potential climate change for the Northeastern US
4. NPCC ¹ (NPCC 2009) New York City Panel on Climate Change (NPCC) Climate Risk Information (CRI), 2009	Report by the NPCC to advise the Mayor of NY City, and the NYC Climate Change Adaptation Task Force on issues related to climate change and adaptation relating to NY City.
5. OCWA ⁴ Orange County, New York, Draft Water Master Plan: Task 2, Strategic Plan, March 2009	The OCWA Water Master Plan. Section 3.3.3 addresses water supply and climate change using results of the analysis by consultants hired by OCWA.
6. NYSERDA New York State Energy Research & Development Authority (NYSERDA) Integrated Assessment for Effective Climate Change Adaptation Strategies in New York State, ongoing, expected publication in 2009	Draft report due out summer 2009. Outline vulnerabilities of NY State to Climate Change, and suggested plans of action. Orange County water will be included as a case study.
7. NYCDEP New York City Department of Environmental Protection (NYCDEP) Integrated Modeling Project, ongoing	Ongoing, state of the art modeling project to identify potential climate change impacts on NY City water supply, including water quality and availability

Table 1. Projects and reports about climate change that are useful for this project. All URLs are active as of April 15, 2009.

¹http://www.nyc.gov/html/om/pdf/2009/NPCC_CRI.pdf

²<http://www.climatechoices.org/assets/documents/climatechoices/confronting-climate-change-in-the-u-s-northeast.pdf>

³<http://www.ipcc.ch/pdf/technical-papers/climate-change-water-en.pdf>

⁴<http://waterauthority.orangecountygov.com/>

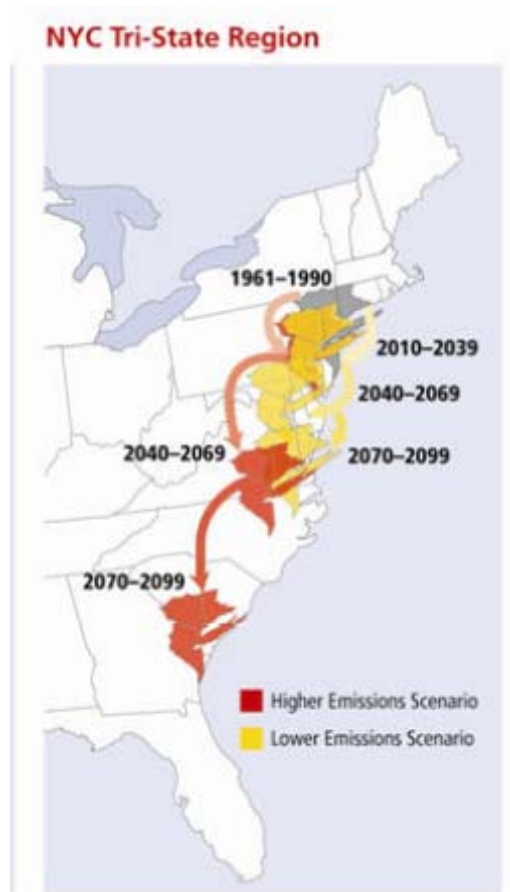


Figure 1. From NECIA (2006). Projected “migration” of summer climate in the Hudson River Valley region based on a heat index.

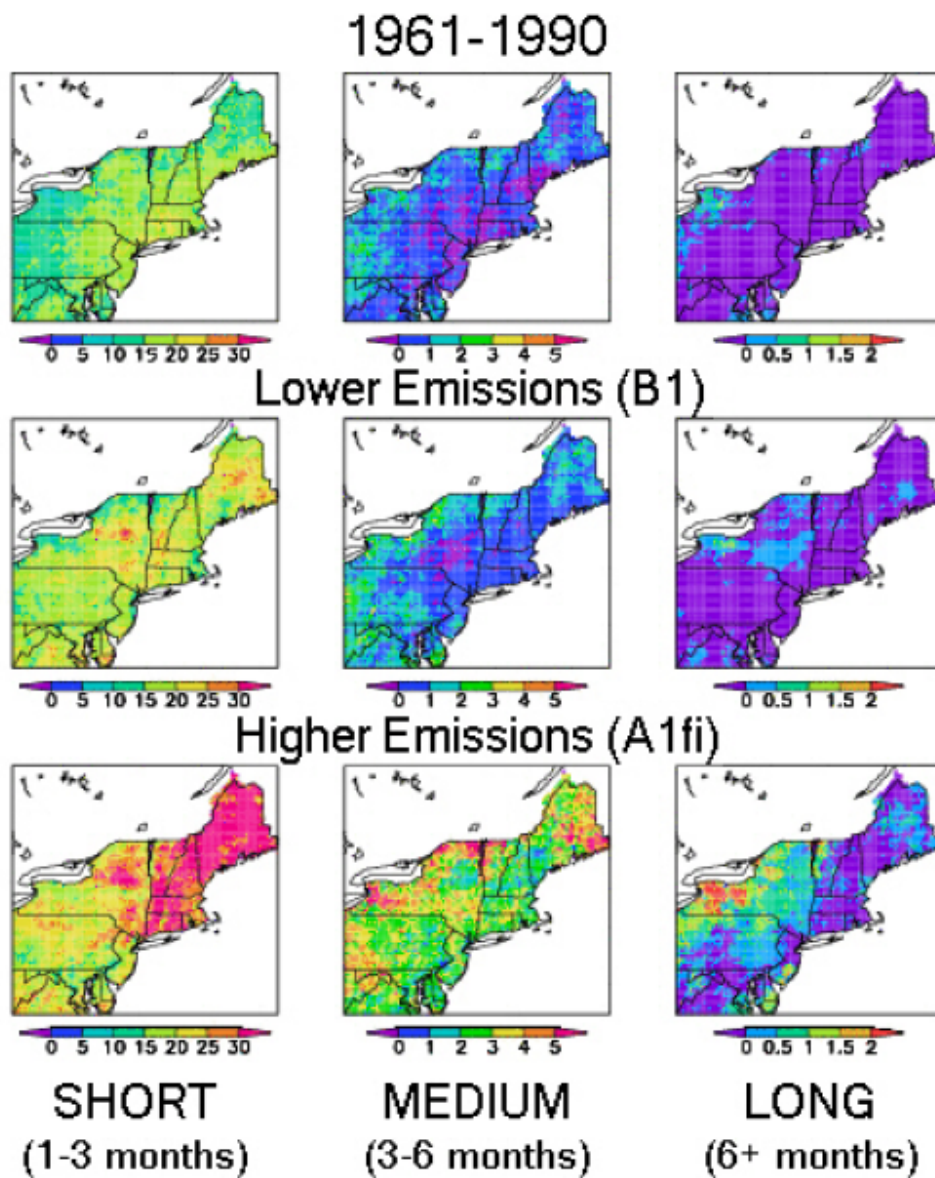


Figure 2. From NECIA (2006). Each map shows the total number of short-term (1-3 month), medium-term (3-6 month) and longterm (6+ month) droughts occurring during the historic 30-year reference period (1961–1990) and the 30-year period at the end of the century (2070–2099) under a higher- and lower-emissions scenario. Projected values are the average of the HadCM3 and PCM based VIC simulations.

FIGURE 11.

Projected Temperature Changes by 30-Year Timeslice.

The maximum and minimum values across the 16 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line

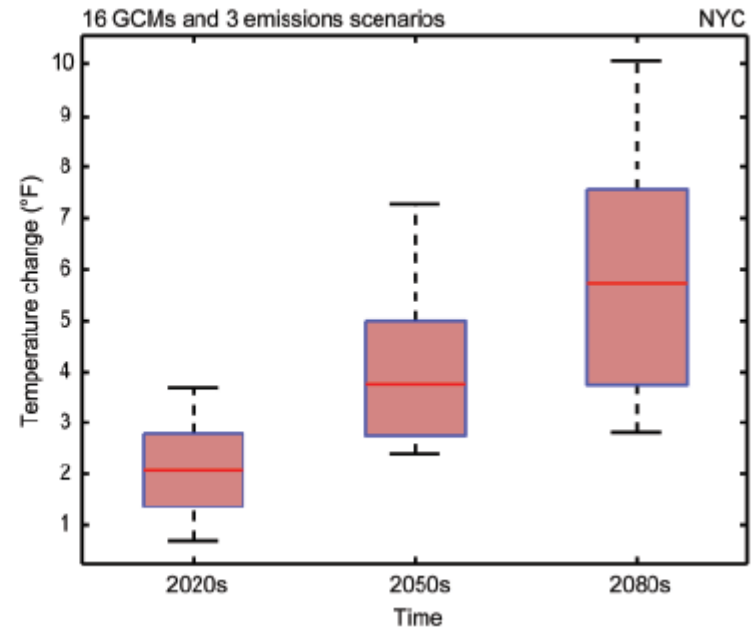


Figure 3. From NPCC (2009) Appendix B.

FIGURE 14.

Projected Precipitation Changes by 30-Year Timeslice

Projected precipitation changes (%) by 30-year time slice. The maximum and minimum values across the 16 GCMs and 3 emissions scenarios are shown as black horizontal lines; the central 67% of values are shown in the shaded areas; the median is the red line.

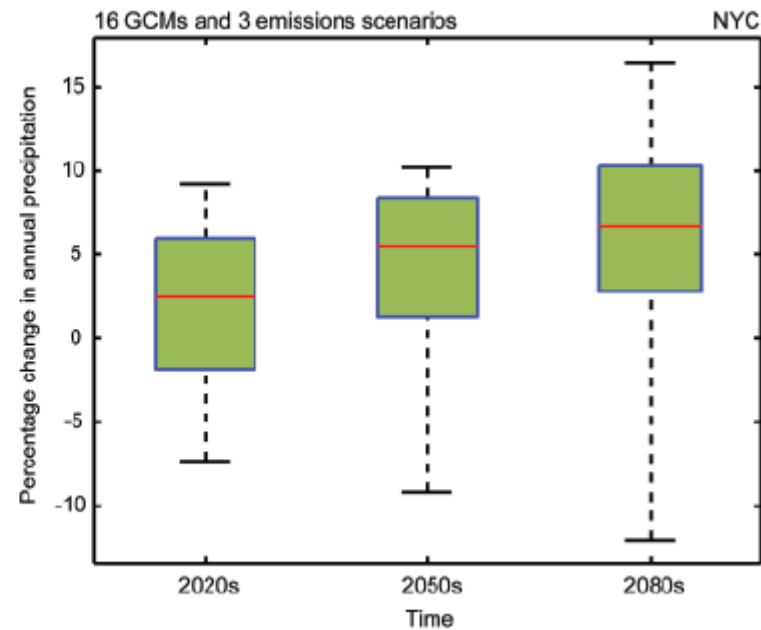


Figure 4. From NPCC (2009) Appendix B.

TABLE 9.

*Baseline Climate and Mean Annual Changes
(Relative to Baseline Years)*

	Extreme Event	Baseline (1971- 2000)	2020s	2050s	2080s
Heat Waves & Cold Events	# of days/year with maximum temperature exceeding:				
	90°F	14	19 (23 to 29) 38	23 (29 to 45) 58	29 (37 to 64) 79
	100°F	0.4 ¹	0.5 (0.6 to 1) 3	0.6 (1 to 4) 8	1 (2 to 9) 19
	# of heat waves/year ²	2	2 (3 to 4) 5	3 (4 to 6) 7	4 (5 to 8) 9
	Average duration (in days)	4	4 (4 to 5) 5	4 (5 to 5) 6	5 (5 to 7) 8
	# of days/year with minimum temperature below 32° F:	72	48 (53 to 61) 66	31 (45 to 54) 56	22 (36 to 49) 56
Intense Precipitation & Droughts	# of days per year with rainfall exceeding:				
	1 inch	13	11 (13 to 14) 15	11 (13 to 15) 16	11 (14 to 16) 17
	2 inches	3	2 (3 to 4) 4	2 (3 to 4) 5	2 (4 to 4) 5
	4 inches	0.3	0.1 (0.2 to 0.4) 0.5	0.2 (0.3 to 0.4) 0.6	0.1 (0.3 to 0.5) 0.7
	Drought occurs, on average ³	~once every 100 yrs	~once every 33 (100 to 100) NA ⁴ yrs	~once every 8 (50 to 100) NA yrs	~once every 2 (8 to 100) 100 yrs

Figure 5. From NPCC (2009) Appendix B. For each parameter, the minimum, central range (including 67% of the projections), and maximum value are shown.

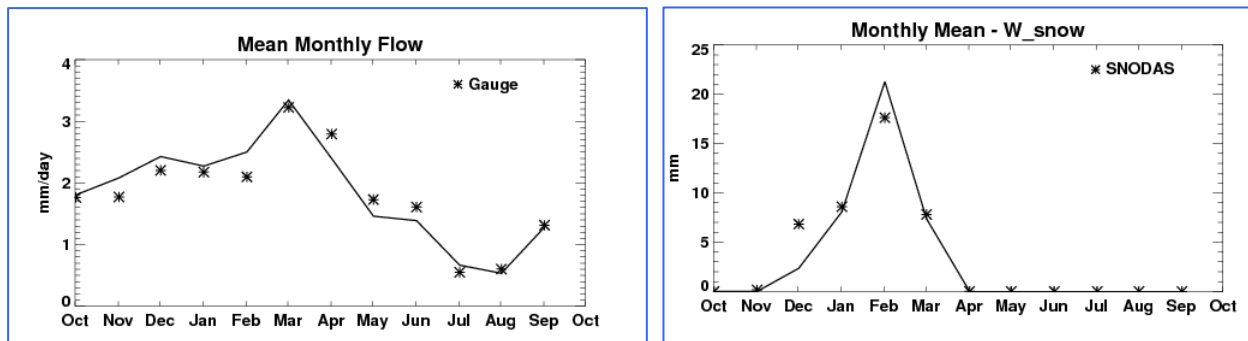


Figure 6. Water balance model validation. Modeled monthly mean streamflow (mm/day) and monthly mean snow pack (mm of water) are shown with solid lines. Asterisks show ancillary data used to verify that model results are realistic. Ancillary gauge data is from the Ramapo River Gage near Mahwah, New Jersey. Ancillary snow pack estimates are from the National Operational Hydrologic Remote Sensing Center (NOHRSC) snow analysis (http://www.nohrsc.noaa.gov/archived_data/). All data is for the period 1999-2008.

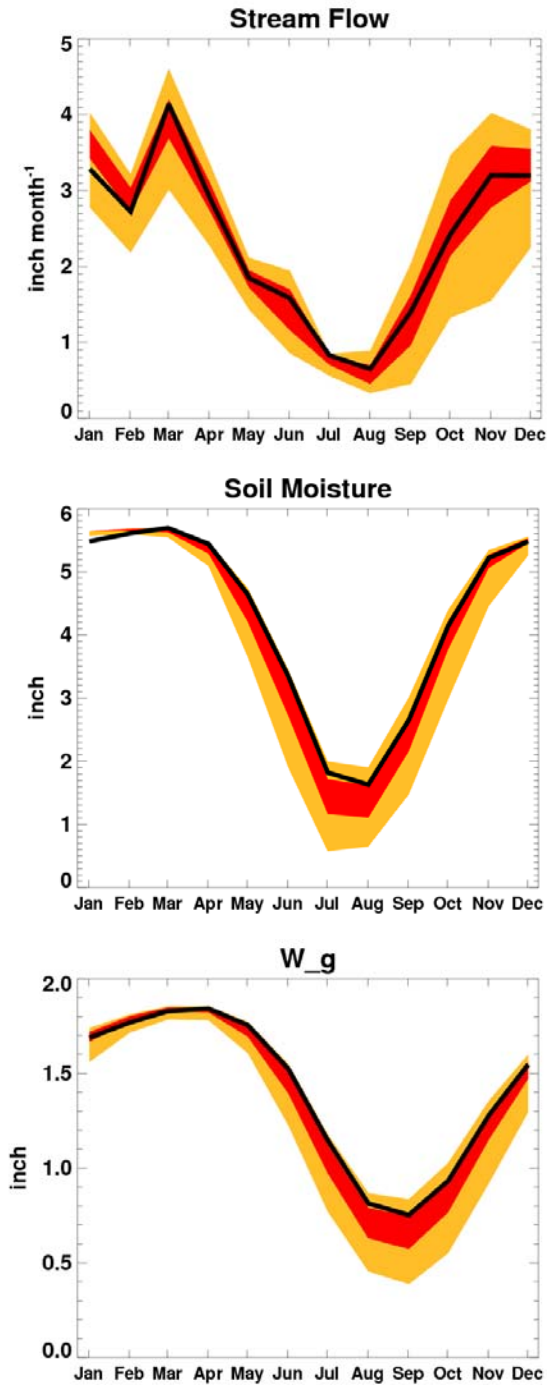


Figure 7. Technical Results obtained for this analysis: Moodna Creek water balance model results for climate change between now and the 2080s. Top panel shows monthly mean streamflow; middle panel shows monthly mean soil moisture; and bottom panel shows monthly mean ground water. Solid black line shows historical period (1997-2008). Red region shows most likely (67%) change, and orange region shows range of potential change, according to the temperature and precipitation changes derived from model results in the NPCC analysis for New York City in the 2080s, and shown in figures 3 and 4 of this report.

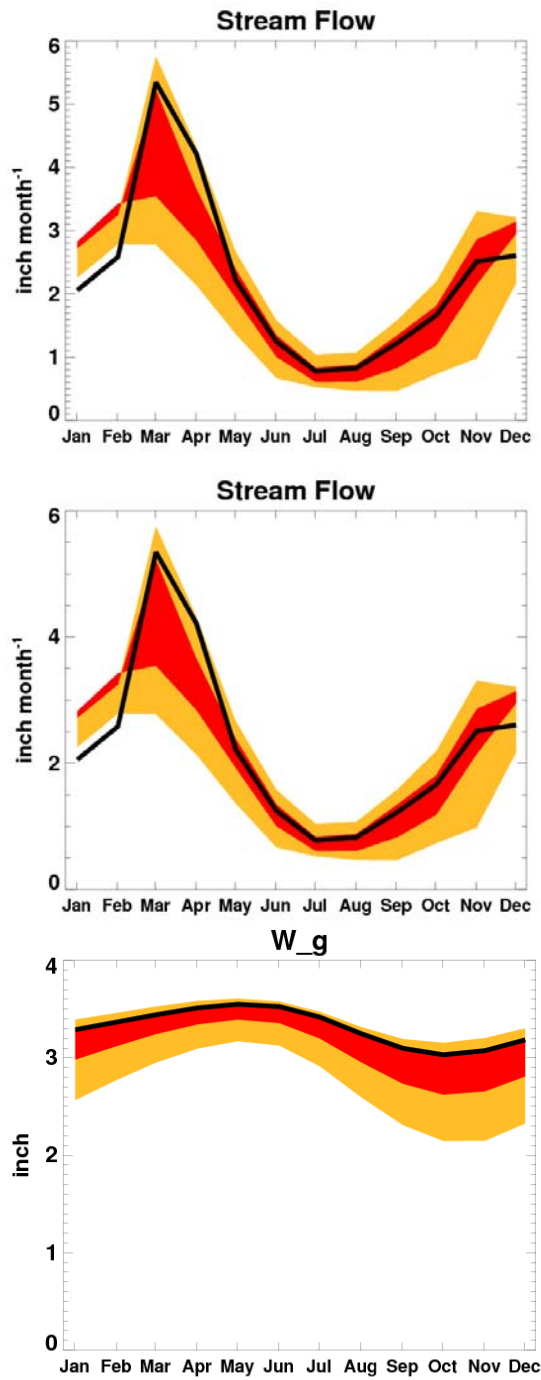


Figure 8. Same as figure 8 except this is for the Canonsville Reservoir in the nearby Catskill Mountains. The time period used for this analysis is 1959-1988.

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Appendix A:
New York State DEC Key Concepts for Climate Change Literacy
(Accepted 10/15/08)

1. The carbon cycle connects all life on Earth.
 2. The greenhouse effect regulates the Earth's temperature.
 3. Some human activities release greenhouse gases (GHG), which intensify the greenhouse effect that causes global warming.
 4. Carbon dioxide generated by human activities is a major cause of global warming.
 5. Global warming leads to climate change.
 6. Many of the variables that constitute our global climate are currently changing more rapidly than at any other time in human history.
 7. Changes consistent with climate change predictions are being observed in New York State.
 8. Scientists predict more dramatic climate change impacts in the next several decades.
 9. The amount of additional climate change we will experience in the future depends on how much we reduce GHG emissions now.
 10. The impacts of climate change on our communities also depend on our ability to adapt.
1. The carbon cycle connects all life on Earth.
 - a. Using energy from the sun, plants, animals and decomposers cycle materials (like carbon) through the environment.
 - b. Plants and animals use carbon to build cells and grow.
 - c. Burning fossil fuels (such as coal, oil and natural gas) releases carbon from the buried remains of plants and animals that lived millions of years ago, and returns it as CO₂ to the atmosphere.
 2. The greenhouse effect is an important factor in regulating the Earth's temperature.
 - a. Warmed by the sun, the Earth radiates heat. Certain gases trap some of this heat in the lower atmosphere.
 - b. The heat-trapping process is called the "greenhouse effect", and the gases are "greenhouse gases" (GHG).
 - c. Natural processes, as well as human actions, generate greenhouse gases.
 - d. The primary natural greenhouse gases are carbon dioxide, methane, and water vapor.
 - e. Without the greenhouse effect, earth would be too cold for humans and other organisms to survive.
 - f. An increase in GHG concentrations causes the atmosphere to trap more heat, which raises global average temperatures.

3. Some human activities release greenhouse gases (GHG), intensifying the greenhouse effect and increasing global warming.

- a. Human activities have increased concentrations of natural GHG like CO₂, nitrous oxide (N₂O) and methane, and added new GHG like halocarbons (compounds of carbon and halogens).
- b. Human actions that release GHG include land use change and burning fossil fuels like coal, oil, and gas for manufacturing, transportation, space heating and cooling, and electricity generation.
- c. Use of fossil fuels, atmospheric GHG concentrations, and temperature have all increased since the Industrial Revolution began 150 years ago.
- d. Scientists first understood the greenhouse effect and predicted a human impact on the earth's average temperature from GHG 100 years ago.
- e. Scientific measurements from around the world prove that the average temperature of earth is increasing.
- f. Most scientists agree that the Earth is warming because of human activities and will continue to warm, but long term predictions vary regarding exactly how much warming will occur, and how fast.

4. Carbon dioxide generated by human activities is a major cause of global warming.

- a. Natural and human processes release carbon dioxide (CO₂).
- b. Since the Industrial Revolution humans have released more carbon dioxide than any other GHG.
- c. Humans have more influence over the release of carbon dioxide than any other GHG.
- d. Currently, the primary reasons for the increase in carbon dioxide in the atmosphere are human use of fossil fuels and land use changes such as deforestation.
- e. Carbon dioxide can last for hundreds of years in the atmosphere, with levels building up over time.
- f. Carbon dioxide levels currently are higher and are increasing more rapidly than at any time in human history.
- g. Proposed state and federal laws aim to reduce the amount of carbon dioxide released into the atmosphere by human activities.

5. Global warming leads to climate change.

- a. Many people use the terms "global warming" and "climate change" interchangeably, to refer to the warmer temperatures being experienced in many parts of the earth and to the changes in climate that these temperatures cause.
- b. Weather refers to specific conditions at any given time. Climate refers to long term patterns of temperature, wind, precipitation, storms, and other variables.
- c. Warmer atmospheric temperatures affect weather -- snow becomes rain; more water evaporates from warmer soil; warmer air can hold more water, making rainfall events more intense.
- d. Warmer atmospheric temperatures cause some weather events to become more frequent and intense, others to become less frequent and intense.
- e. Changes in average weather over a long time period indicate climate change.
- f. As the Earth warms, it triggers the release of additional stored GHG from the Earth (feedback).

6. Many of the variables that constitute our global climate are currently changing more rapidly than at any other time in human history.
- The Earth's climate changes over time.
 - Life on Earth is shaped by, depends on, and affects climate.
 - Historic and current emissions of GHG make some amount of additional climate change unavoidable.
 - Scientists agree that the earth's climate is changing, but long-term predictions vary regarding the rate and extent of change.
 - As of 2007, 11 of the last 12 years (1995-2006) ranked among the 12 warmest years in the record of global surface temperature since 1850.
 - The warming trend over the last 50 years (0.13 degrees C/decade) is nearly twice that for the last 100 years.
7. Changes consistent with climate change predictions are being observed in New York State.
- Observations show that the effects of climate change are different in different regions on Earth.
 - New York State's average temperature has gone up 2°F in 30 years.
 - Of New York's seasons, winters are warming fastest (5°F in 30 years).
 - Scientists have documented that the ranges of several species are moving northward, suggesting a response to changing climate.
 - Bloom dates of many species are 4 to 8 days earlier on average, and the last frost date is two weeks earlier, affecting food webs and farming.
 - In many parts of the state, average rainfall is increasing, while snowfall is decreasing.
 - Sea level in New York Harbor is fifteen inches higher today than it was in 1850.
8. Scientists predict more dramatic climate change effects in New York in the next several decades.
- Some extreme weather events are predicted to become more intense (no change in the intensity of snowstorms is predicted).
 - Shorter, warmer winters and longer, hotter summers will change conditions for recreation and tourism.
 - Changes in rainfall and average temperatures will affect both local and imported food supplies.
 - Rising sea levels and increased flooding from storms will threaten shorelines and waterfronts, affecting infrastructure, transportation, properties, businesses, and habitats.
 - Rising summer air temperatures will increase pollution-related asthma, heat exhaustion, and tropical diseases carried by insects moving northward.
 - Changes in regional climate and atmospheric CO₂ levels will favor invasive species and nuisance plants.
 - Climate-induced changes in habitats like wetlands and forests threaten wildlife, water quality and quantity, and forest products.

9. The amount of additional climate change we will experience in the future depends on how much we reduce GHG emissions now.

- a. Reducing the amount of GHG we release into the atmosphere will decrease the risk of the most severe impacts of climate change.
- b. The most effective way we can reduce GHG emissions is to improve energy efficiency and adopt low- or no-carbon sources of energy.
- c. Personal decisions all help: change light bulbs, carpool, recycle, buy less, eat locally produced food, conserve water, insulate your home, and turn off lights and appliances.
- d. Low carbon energy sources have added benefits, including reduced air pollution, lower fuel costs, energy independence, and new green technology jobs.
- e. Choosing products with low life cycle CO₂ emissions will help reduce greenhouse gases. (Life cycle includes raw material extraction, production, distribution, use and disposal).
- f. Thirty years ago, scientists, governments, and industries worked together and reduced the harmful chemicals destroying the ozone layer. We did it before and we can do it again.

10. The impacts of climate change on our communities also depend on our ability to adapt.

- a. Humans will have to adapt to some amount of climate change.
- b. Current social and economic systems assume a stable climate; Adapting to climate change requires building flexibility and resilience into planning for the future.
- c. The sooner we reduce the amount of GHG we emit, the less risk we'll face in the future.



Climate Change “Key Concepts” Resources

Intergovernmental Panel on Climate Change

- Summary for Policymakers of the Fourth Assessment Report and the Frequently Asked Questions document. Both documents are accessible from the IPCC website (<http://www.ipcc.ch/>), with the Summary available from the IPCC home page and the FAQ found at <http://ipcc-wg1.ucar.edu/>

National Academy of Sciences

- Understanding and Responding to Climate Change, downloadable at <http://dels.nas.edu/basc/climate-change/basics.shtml>

Union of Concerned Scientists (UCC)

- Climate Change in the Northeast: A Report of the Northeast Climate Impacts Assessment, October 2006
- The Changing Northeast Climate: Our Choices, Our Legacy
- Reducing Heat-Trapping Emissions in the Northeast
- New York: Confronting Climate Change in the U.S. Northeast
- Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions (Executive Summary)
- Global Warming section on website (solutions, early warning, sound science initiative pages)
http://www.ucsusa.org/global_warming

American Association for the Advancement of Science (AAAS)

- Communicating and Learning About Climate Change: An Abbreviated Guide for Teaching Climate Change, From Project 2061 at AAAS
- AAAS Board Statement on Climate Change

National Oceanic and Atmospheric Administration (NOAA)

- Climate Literacy: Essential Principles and Fundamental Concepts, Formal & Informal Education (Draft document)

United Nations Environment Program (UNEP) and United Nations Framework Convention on Climate Change (UNFCCC)

- Climate Change Information Kit (An Introduction to Climate Change)

Arctic Climate Impact Assessment

- Impacts of a Warming Arctic (Highlights Document)

The University Corporation for Atmospheric Research (UCAR) Website

- Understanding Climate Change: Global Warming FAQs
<http://www.ucar.edu/news/features/climatechange/faqs.jsp>

Clean Air – Cool Planet Website

- What Does Global Warming Mean for the Northeast?
<http://www.cleanair-coolplanet.org/information/implications.php>

Teachers’ Guide to High Quality Educational Materials on Climate Change and Global Warming Website

- <http://hdgc.epp.cmu.edu/teachersguide/teachersguide.htm>

World Wildlife Fund (WWF)

- Your Climate, Your Future: An interdisciplinary approach to incorporating climate change in your classroom (lesson plans for grades 9-12)

Information Transfer Program Introduction

The New York State WRI devotes much of its resources to assisting state and local governments address complex challenges to sustainable water resources management. Under its new Director, Prof. Susan Riha, WRI continues its long-standing partnerships with organizations such as the Hudson River Estuary program while also forging new relationships with organizations such as the Nature Conservancy and NYSERDA (New York State Energy Research and Development Authority). Most of our newer partnerships are oriented towards emerging challenges facing New York State. In FY08, WRI concentrated its efforts on three of these challenges: climate change, natural gas drilling in the Marcellus Shale, and reactive nitrogen in the environment. To more effectively scale our efforts, the WRI website (<http://wri.eas.cornell.edu/>) has been completely redesigned in order to provide timely and accessible information to a range of water resources stakeholders in New York State.

Director's Office Information Transfer

Basic Information

Title:	Director's Office Information Transfer
Project Number:	2008NY108B
Start Date:	3/1/2008
End Date:	2/28/2009
Funding Source:	104B
Congressional District:	22
Research Category:	Not Applicable
Focus Category:	Climatological Processes, Water Quality, Waste Water
Descriptors:	
Principal Investigators:	Susan Riha

Publication

1. Lauren, J.G. and S.J. Riha. 2009. Critical Needs for Reducing Reactive Nitrogen in New York State: A Policy Brief from the Water Resources Institute.

Current Partnership Programs

- *Hudson River Estuary Program* – Funded by the NYS Department of Environmental Conservation (DEC), the program is guided by 12 goals as part of its Action Plan formed in 1996. These goals address signature fisheries, river and shoreline habitats, plants and animals, streams and tributaries in the entire watershed, landscape and scenery, public access, education, waterfront revitalization, water quality, and partnerships and progress. WRI and DEC work together to protect this rich estuary ecosystem that is a source of municipal drinking water, spawning grounds for migratory fish, habitat for bald eagles, and an excellent recreation area for boaters, anglers and swimmers.
- *NY Project WET (Water Education for Teachers)* – Funded by the DEC for the seventh year, staff provide annually over 55 formal workshops, training approximately 900 teachers and educators in basic water education. Project WET's mission is to facilitate and promote awareness, appreciation, knowledge and stewardship of water resources. Many of the approximately 200 activities in the K-12 Curriculum Guide are correlated to the NY State Education Curriculum. The activities promote critical thinking and problem solving skills, providing a thorough water education program.

Emerging Issues

- *Reactive Nitrogen in New York State*

An important focus for Information Transfer is management measures to meet and sustain water quality standards. A critical need is to foster local understanding of scientifically sound management of land use and nonpoint sources to predictably and reliably restore these water-bodies to their designated uses. The Water Resources Institute has convened several roundtables to discuss emerging issues, management strategies and critical areas for policy and research related to the problem of excessive levels of reactive nitrogen in the waters of New York State. Key regions/topics considered include: the Upper Susquehanna Watershed, the Peconic Estuary, manure management in New York's dairy belt, and acid lakes in the Adirondack and Catskill regions. Julie Lauren (WRI Senior Research Associate) is in the process of summarizing these discussions and developing a white paper for state legislators and others in order to raise awareness on the urgent need to reduce reactive nitrogen levels in New York State waters.

- *Natural Gas Development in New York State*

Natural gas is found in many sedimentary rock formations, but many of these reserves cannot be profitably developed with standard drilling techniques. Recent technological advances in horizontal drilling and hydro-fracturing (high-pressure rock fracturing) have made the exploitation of the so-called 'tight' shale formations extremely attractive. One of these formations is the Marcellus Shale, and the most promising portions of this formation lie beneath the Southern Tier of New York and in Northern Pennsylvania. Some estimates suggest that the Marcellus may become the largest natural gas 'play' in the world. The potential scale and pace of drilling in the Marcellus coupled with the massive water requirements (2-3 million gallons per well) for hydro-fracturing and the concomitant requirements for wastewater disposal may have far-reaching implications for New York State's water resources. Recognizing that the current regulatory framework is ill-equipped to cope with the development of the Marcellus Shale, Governor Paterson authorized the NYS Department of Environmental Conservation to add a supplement section to the Generic Environmental Impact Statement (sGEIS) that covers gas well development in New York. The New York State Water Resources Institute (WRI) has taken an active role in the assessment and debate surrounding the Marcellus shale. Specifically, WRI has: 1) Facilitated a meeting between the NYS DEC's Division of Water, NYS Bureau of Mineral Resources, several Cornell University faculty, and scientists from the NY USGS; 2) Served as key public information portal for explaining potential environmental impacts of gas well drilling in New York (<http://wri.eas.cornell.edu/wrihomepage.html>); 3) Provided expert testimony on gas well drilling to NYS

Assembly's standing committee on environmental affairs; and 4) Coordinated a response to the scoping document that will determine the potential impacts addressed in the sGEIS.

• *Sustainably Managing Water Resources in a Changing Climate*

Despite the wealth and diversity of water resources in New York State, nearly 800 waterbodies are currently deemed impaired and emerging threats from climate change are bringing into sharper focus current issues of concern such as flood damage (\$54 million in 2006), insufficient municipal water supplies (desalination proposed in lower Hudson), aging wastewater infrastructure, and new sources of consumptive water use like gas well drilling. Climate change projections for New York suggest an increase in the frequency and magnitude of extreme precipitation events coupled with higher probabilities of damaging summer droughts. Other potential changes include a heightened risk of soil erosion (and other forms of non-point source pollution) resulting from a reduction in winter snowpack. New York State is proactively engaged in addressing the challenges posed by climate change and recently awarded a group of scientists from Cornell and Columbia Universities a contract to conduct a state-wide vulnerability assessment and to identify opportunities for building resilience to anticipated changes. As part of this effort, with Cornell's Rebecca Schneider, Susan Riha and Andrew McDonald (WRI Research Coordinator) are co-leading the water resources sector. Municipal planners, natural resource managers, and many business owners will benefit from sector-specific risk management strategies that address these challenges. WRI is working to catalyze partnerships between academics, state agencies, and the cooperative extension system to advance the science and best practices to achieve sustainable water resource management in a changing climate.

Student Public Service Activities

Students and interns are supported in several ways through WRI:

- Competitive Grants Program – each grant provides for at least one graduate or undergraduate student to work under faculty supervision on priority problems in New York State;
- Hudson River Estuary Program – internships are sought through the Student Conservation Association each year for at least one graduate, undergraduate or high school student to work with WRI staff.
- Project WET (Water Education for Teachers) – Interns are employed from local colleges to assist WRI staff in preparing for workshops and events, and working at State-run Environmental Education Centers on water education activities.

Student Support					
Category	Section 104 Base Grant	Section 104 NCGP Award	NIWR-USGS Internship	Supplemental Awards	Total
Undergraduate	7	0	0	0	7
Masters	1	0	0	0	1
Ph.D.	3	0	1	0	4
Post-Doc.	1	0	0	0	1
Total	12	0	1	0	13

Notable Awards and Achievements

Andrew McDonald (WRI Research Coordinator) and Susan Riha (WRI Director) are co-chairing the water resources component of an ongoing project to assess climate change vulnerabilities and opportunities for adaptation in New York State. This is a multi-sector (Water, Agriculture, Coastal Zones, Public Health, Energy, Transportation, and Communications) and multi-institution (Cornell, Columbia, Hunter) project funded by the New York State Energy Research Authority (NYSERDA). Monies from our base grant were utilized to initiate a program on climate change and water resources which, in turn, directly contributed to our success in securing competitive funding from NYSERDA.

Publications from Prior Years

1. 2005NY64B ("Export of atmospheric nitrogen deposition from forests at the top of the Susquehanna watershed") - Articles in Refereed Scientific Journals - Goodale, C.L. et al. 2009. Unusual seasonal patterns and inferred processes of nitrogen retention in forested headwaters of the Upper Susquehanna River *Biogeochemistry* 93:197–218.